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ABSTRACT

This student manual contains the textual material for a seven-lesson unit on activated sludge. Topic areas addressed in the lessons include: (1) activated sludge concepts and components (including aeration tanks, aeration systems, clarifiers, and sludge pumping systems); (2) activated sludge variations and modes; (3) biological nature of activated sludge; (4) sludge quality and respirometry for process control; (5) return sludge control; (6) waste sludge control; and (7) trend charts, testing, and data management. A list of objectives for each lesson, a glossary of key terms, a list of references, and a worksheet for each lesson are included. (JN)

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Biological Treatment Process Control

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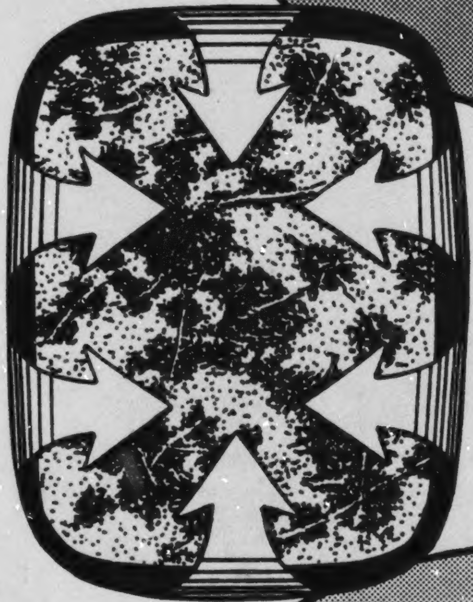
Activated Sludge



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Linn-Benton Community College
Albany, Oregon 1984

BIOLOGICAL TREATMENT PROCESS CONTROL

ACTIVATED SLUDGE

STUDENT MANUAL

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ACTIVATED SLUDGE

Student Manual

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ACTIVATED SLUDGE

Objectives

At the completion of this unit you should be able to:

Lesson 1:

1. Explain the activated sludge process.
2. Give the names of the two chemists that discovered the activated sludge process.
3. Listthe three control variables for activated sludge.
4. Identify the basins and flows of an activated sludge system.
5. List the types of aerators used.
6. Give the advantages and disadvantages of different types of aeration systems.
7. Describe the use of pure oxygen.
8. Name the two clarifier designs.
9. State the design range for surface loading and weir loading of secondary clarifiers.
10. List two methods of sludge removal in secondary clarifiers.

Lesson 2:

1. List the 3 major process variables.
2. List the 4 classic loading variations.
3. Give the F/M ratio ranges for the loading variations.
4. Describe the loading variations in terms of sludge age and sludge yield.
5. Draw and label flow diagrams of the loading variations.
6. Calculate loading factor.
7. Describe the complete mix, step aeration, tapered aeration and plug flow operational modes.

Lesson 3:

1. Define good quality sludge.
2. List the organisms found in activated sludge.
3. Give the two main uses for energy derived from organic food.
4. Define adsorption and absorption.
5. Describe the process of cellular respiration.
6. Explain endogenous respiration.
7. Explain how protozoa can be used to determine the status of the bacterial population.
8. Give the characteristics of young and old sludge.
9. Describe pin floc and straggler floc.
10. Explain what is meant by a two-sludge system.
11. Describe how filaments affect sludge quality.

Lesson 4:

1. Describe the oxidation pressures that affect sludge quality.
2. Define respiration rate.
3. Give BOD loading ranges for high rate, conventional and extended aeration systems.
4. Explain how sludge yield is defined.
5. Calculate SVI.
6. Give characteristics of over and under oxidized.
7. List visual characteristics assessed at the aeration basin and final clarifier.
8. Distinguish between hydraulic washout and bulking sludge.
9. Describe how respirometry can be used to aid in operational control decisions.

Lesson 5:

1. Give the purpose of return sludge control.
2. Define CSFD, RSF, and RSC.
3. Calculate RSF, CSFD, SSC, and SSV.
4. Plot SSC and SSV.

Lesson 6:

1. Give the purpose of waste sludge control.
2. Define sludge inventory.
3. List the questions that a materials balance program should answer.
4. List the 9 methods used to evaluate the presence of excess sludge.
5. Indicate the wasting trend needed in response to F/M, MLVSS, MCRT, and sludge age.
6. Describe the use and value of trend charting.
7. Calculate wasting rate on the basis of MCRT, F/M, MLVSS and sludge age.

Lesson 7:

1. Describe and construct moving average trend charts.
2. List and describe the lab tests used in activated sludge process control.

Lesson 8:

1. Analyze the situation of an activated sludge plant and recommend short and long term operational modifications.

ACTIVATED SLUDGE

Glossary

Absorption - The use of oxygen, water, and organic matter for the metabolism of the organism.

Activated Sludge - Activated sludge is a brownish floc-like material consisting largely of organic matter obtained from the sewage. This material is inhabited by millions of bacteria and other forms of biological life, mainly aerobic in nature.

Adsorption - The adherence of dissolved, colloidal or finely divided solids on the surface of the solid bodies with which they are brought into contact.

Aeration - The bringing about of intimate contact between air and liquid by one of the following methods: spraying the liquid into the air; bubbling air through the liquid, or by agitation of the liquid to promote surface adsorption of the air; or any combination of these methods.

Aerator - A structure, round or rectangular, built for the purpose of aerating and mixing activated sludge liquor.

Aerobic - Bacteria which require free (elemental) oxygen for their growth.

Air Cleaner - A device for removing foreign material from the air that is to be used for aeration through diffusers.

Air Diffusers - Devices for breaking up air into fine bubbles in water for the purpose of transferring a part of the oxygen in the air to the liquid surrounding the bubble.

Biochemical Oxygen Demand - The amount of oxygen that will be required for the stabilization of organic matter through biochemical action at a given time and temperature.

Biosorption - An application of the activated sludge process where the returned activated sludge is aerated for a prolonged time.

Conventional A. S. - An aerobic biological sewage treatment process in which a mixture of sewage and activated sludge is separated from the treated sewage (mixed liquor) by sedimentation and wasted or returned to the process as needed. The treated sewage overflows the weir of the settling tank in which separation from the sludge takes place.

Denitrification - The oxidation of ammonia nitrate to nitrites, nitric acid and nitrogen gas.

Detention Time - The time it takes to fill a tank at a given rate of flow.

Diffuser - A device which divides air into minute bubbles for diffusion into liquids.

Dissolved Oxygen - Usually designated as D.O. The oxygen dissolved in sewage, water, or other liquid usually expressed in mg/l or percent of saturation. The amount of free gaseous oxygen held in water.

Factor - Frequently a ratio used to express operating conditions such as loading or power factors.

Fission - The division of the BOD into two parts each growing into complete organisms.

Floc (Activated) - Small particles of zoogleal slime and activated sludge joined together to form a mass about the size of small snowflakes. They are heavier than water and must be kept in motion to prevent settling.

Flocculation - The coming together of minute particles in a liquid.

Flow Through - A liquid entering one end of a tank and leaving by the other end.

Hi-Rate Activated Sludge - A new variation of the conventional activated sludge process where faster and better treatment can be obtained through better controls.

Mechanical Aeration - The transfer of oxygen from the air to the liquid by mechanical means. Such as mixing, spraying or pumping.

Metabolism - The ability of the organisms to break down biochemically complex organic matter into more simple compounds that can then be used by the organism for his growth and reproduction.

Mixed Liquor - The contents of the aeration chamber.

Mixers - Mechanical equipment designed to mix the liquor in the aerator.

MLSS - Mixed liquor suspended solids. The volume of activated sludge in the aerator.

Nitrification - The oxidation of ammonia nitrogen into nitrates through biochemical action.

Overaeration - Where such an excess of D.O. is present in the aerator that denitrification sets in.

Oxygen Demand - The oxygen required for the normal respiration of the aerobic organisms plus the oxygen required for the reduction of the unstable matter in sewage.

Oxygen Transfer - The amount of oxygen that can be transferred from the air to the liquid.

Oxygen Uptake - The rate in which the available D.O. is used by the MLSS.

Plant Balance - When all factors such as food supply, MLSS, D.O., and detention time are in the correct proportions, the plant is said to be in balance.

Pre-Aeration - A preparatory treatment of sewage, comprising aeration to add oxygen to the sewage, to promote the flotation of grease and to aid coagulation of the solids.

Process - A sequence of operations.

Reaeration - The absorption of oxygen by a liquid where the D.O. has been depleted, such as reaerating the returned activated sludge for considerable time to promote the aerobic digestion of the solids adsorbed. Use with the biosorption activated sludge process.

Recirculation - The absorption of oxygen by a liquid where the D.O. has been depleted, such as reaerating the returned activated sludge for considerable time to promote the aerobic digestion of solids adsorbed. Use with the biosorption activated sludge process.

Returned Activated Sludge - The amount of activated sludge that is to be recycled through the aerator from the final clarifier.

Sludge Blanket - The distance under the surface of the final clarifier the settled sludge is lying.

Sludge Bulking - When the weight of the activated sludge floc becomes lighter than water, the sludge will float out of the final clarifier. Bulking sludge will have a very disagreeable odor, be light gray in color and have a very high SVI. This condition is caused by the plant being out of balance or by some toxic material in the sewage.

Sludge Loading - A ratio of pounds of organic matter in the primary effluent to the pounds of MLSS.

Sludge Volume Index - The sludge volume index is the volume in milliliters occupied by one gram of activated sludge after settling for thirty minutes.

Sparger - The air distribution device used with mixers for aeration of the mixed liquor in the hi-rate activated sludge process.

Step Aeration - A variation of the conventional activated sludge process where the settled sewage is introduced into the aerator at several different points along the aerator. This is done to improve the mixing and to minimize shock loads.

Suspended Solids - Solids physically suspended in sewage which can be removed by proper laboratory filtering.

Volatile Solids - Volatile solids are those solids that are burned off after being burned at 600° C for 15 to 20 minutes.

ACTIVATED SLUDGE

Lesson 1 - Review of Concepts and Components

Concepts

Activated sludge is a treatment process that has been with us for quite some time. The understanding of the activated sludge process and the operation of that process, however, has developed slowly. One of the challenges has been in understanding the ability of sludge to treat sewage. By the end of the late 1800's, wastewater treatment was fairly well established in most major cities. The first major concern of wastewater treatment, at that time, was settling and removing solids from the sewage.

A second concern was the removal of odors from the treatment systems. This concern led scientists to learn that blowing air into a sewage stream would help reduce or eliminate odors. This discovery was found to be very useful in closed or contained systems where odors were very severe. Studies done in Europe continued this effort. A series of studies were conducted in 1914 by Ardern and Lockett. Ardern and Lockett were chemists who worked in a treatment plant in England. When they conducted tests in their laboratory, they discovered that flocculated sludge particles which have the ability to form a larger mass from many fine suspended particles developed in their treatment tests. It was also observed that as the quantity of flocculated sludge increased, the degree of treatment improved. This new relationship was the start of a long and successful history of the activated sludge process. They wrote and published a paper that identified this material as "activated sludge". The original definition of activated sludge was the ability to purify sewage through the use of flocculated solids in the presence of air. The term "activated" is the key of this newly discovered process. Neither Ardern nor Lockett understood what was happening but they knew that treatment was occurring far greater than should be expected from just the physical ability of settling solids from the water.

Scientists and engineers immediately began to take advantage of this concept by applying it to full-scale wastewater treatment plants. Even with extensive use of the process, it was not until the 1930's that scientists began to understand the nature of the flocculated solids. At this time, the general consensus emerged that the flocculated solids were the result of biological activity, and that these flocculated biological solids utilized oxygen from the air being provided to biologically treat the sewage. As simple as it may sound, this represented a major breakthrough in the understanding of the activated sludge treatment process, because a relationship of oxygen to the biological material represented a firm and distinct control mechanism for wastewater treatment. The same considerations led to the understanding that production of excess solids was the result of biological growth. This concept again was very basic in the original studies of activated sludge; yet, without the tie to the biology of the system, the accumulation of excess solids was more of a by-product than that of a production. The concept of production provided another major control mechanism for the process. We now call this production of excess solids the sludge yield. Therefore, the second major control element of the activated sludge process is the wasting of the excess solids or wasting the yield from the process.

A third major control variable that emerged was the return of settled sludge from the clarifiers to the aeration tanks. Again, this concept was very simple in concept but very critical to the success of the process. Without the use of return sludge, there could be no accumulation of activated sludge in the aeration tank than could be grown during any single pass of the sewage through the aeration tank. By returning sludge from the clarifier, an increased quantity of activated sludge could be provided without increasing tank size. Figure 1, a diagram of a typical activated sludge wastewater treatment plant, identifies the three major control mechanisms for the activated sludge process: air supply, waste sludge control and return sludge control.

The activated sludge process is now defined as the treatment of sewage through the use of the suspended biological solids whose activity and quantity is controlled by the addition of oxygen, by the wasting of excess solids and by the recycle of settled solids in the clarifier. This process when operated properly will provide clear and sparkling effluent of very high quality. The goal of operating an activated sludge plant is to consistently produce this effluent of high quality in the most efficient

THE ACTIVATED SLUDGE PROCESS

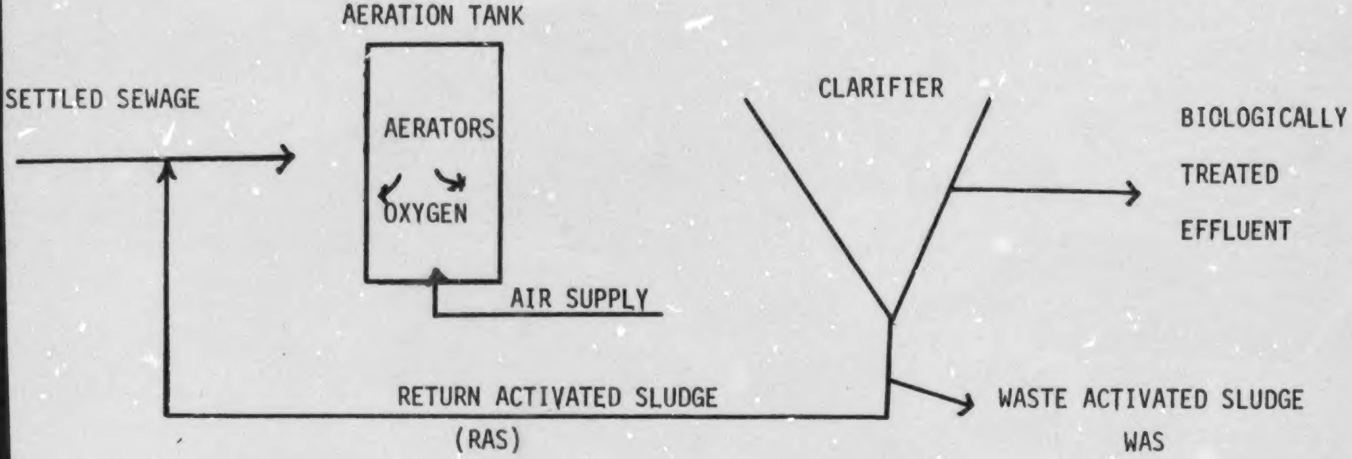

AERATION TANK
SETTLED SEWAGE
AERATORS
OXYGEN
AIR SUPPLY
CLARIFIER
BIOLOGICALLY
TREATED
EFFLUENT
RETURN ACTIVATED SLUDGE
(RAS)
WASTE ACTIVATED SLUDGE
WAS

FIGURE 1

manner possible. Specific performance standards are identified in the National Pollution Discharge Elimination System (NPDES) permits. Compliance with effluent standards should always be the first objective of a good operator. But a good operator should also be concerned with optimum operation to protect the mechanical equipment and maintain the biological workers in the system.

This brief overview of the activated sludge concepts has provided a definition of activated sludge and has identified the major control issues of an activated sludge system. These are the control of dissolved oxygen feed, wasting the excess solids or the yield from growth, and returning settled sludge from the clarifier.

Components:

Mechanical Aerators

Mechanical aerators are common to many small and some large treatment plants. Mechanical aerators include the plate type, the up-draft, down-draft types, and floating types.

Some advantages of the mechanical aerator are:

(1) elimination of many protrusions in the aeration tank such as piping, diffusers, valves, etc.

(2) generally low maintenance

(3) flexibility over wide ranges of conditions

The efficiency of mechanical aerators is usually expressed in terms of pounds of oxygen transferred at standard conditions per hour per break horsepower. Standard conditions include 20°C for temperature and zero mg/l for dissolved oxygen. Common theoretical efficiencies for large mechanical aerators are 2.0 to 4.0 pounds O_2 transferred under standard conditions per hour per horsepower. Actual efficiencies should be verified by field testing.

Plate-type Mechanical Aerators

These units consist of a circular flat plate with vertical blades attached at the periphery of the plate. Oxygen transfer occurs when the plate creates a peripheral hydraulic jump. It accomplishes a high degree of oxygen transfer through entrainment of air in the mixed liquor. Features that affect oxygen transfer include the diameter of the plate, size of the vertical blades, the number of blades, the speed of rotation, and the submergence of blades in the water. Under ideal operating conditions the spinning plate actually becomes completely free of the liquid. Under these conditions, air is drawn down past the top plate and aerates the flow of the water as it is pulled up out of the basin.

Updraft Aerators

These aerators have an impeller located at the surface of the liquid which is designed to pump large quantities of liquid at a low head. Individual blades attached to the rotating drive train are designed specifically to ensure maximum hydraulic efficiency. The updraft effect of the aerator works exactly like a pump. The high pumping rate or turnover rate provides for frequent contact of mixed liquor with the air and the high velocities maintained in the basin help maintain solids in suspension. As the liquid falls back to the aeration tank, the majority of oxygen transfer occurs. The turbulence in the surface liquid also helps to trap air bubbles which provides for further oxygen diffusion. The updraft type aerators can be mounted on rigid platforms or mounted on flotation devices. On some of the updraft aerators, there may be a deflection plate above the impeller which deflects the volume of water being pumped upward. This deflection plate helps disburse the liquid to increase transfer and in cold climates it can help prevent the buildup of ice on the support structures of the aerator. The addition of draft tubes located immediately below the impellers and extending from a couple feet in some cases to the bottom of the aeration tank in other cases helps draw the mixed liquor from the bottom reaches of the tank to ensure or to minimize depositing of solids in the aeration tank.

Downdraft Aerators

Downdraft aerators have similar principle of operation as the updraft aerators except they work in reverse. In this case, the impeller forces liquid from the top of the aeration tank, down through a draft tube to the bottom of the aeration tank. The liquid entrains air from the surface of the aeration tank and then carries it down through the draft tube and disperses throughout the bottom of the aeration tank. The rotating impeller pumps downwards and induces a negative pressure immediately above the impeller which helps to draw air into the pumped liquid.

Combination Type Aerators

The typical combination type aerators include surface impeller action as well as a submerged impeller. An air sparger diffuser is located below the submerged turbine which disperses air immediately into the mixed liquor. The rotating action of the turbine breaks up the air into small bubbles and then the mixing from both turbine blades mixes the air bubbles throughout the tank. The use of the surface turbine may or may not be part of a particular manufacturer's equipment line but when supplied it provides additional oxygen transfer capabilities on the surface of the tank similar to the updraft aeration system. One of the critical features of the combination type aerators is the alignment and support of the extended shaft which connects the turbines to the motor. The major advantage of the combination type aerators is that they provide for a separation of the mixing energy requirement from that of the oxygen energy requirement. This dual system provides flexibility for the operator to optimize these two actions.

Brush-type Aerators

Many small activated sludge treatment plants utilize the rotating brush type aerator. Generally these units consist of a horizontal revolving shaft with combs, blades, angles, or some type of aperture attached to the shaft and extending slightly below the water surface. The rotation of the shaft forces oxygen into the liquid and then carries liquid into the air where it further contacts and entraps oxygen bubbles. These types of units have been reported to be very efficient for oxygen transfer.

Diffusers

Diffusers are devices that provide for the introduction of air into the mixed liquor. They can be used for the very small plant or for the very large treatment plant. Diffusers are installed in various locations and arrangements below the liquid surface of the aeration tank. Either fixed or retractable mountings are used to support the diffusers. The air is furnished by blowers which operate at pressure sufficient to overcome the static head of the liquid above the diffusers. Diffusers are classified as porous and non-porous. Porous diffusers such as plates or tubes are either of a ceramic type material constructed of silicon dioxide or aluminum oxide grains held in a porous mass with a ceramic binder, or of a non-ceramic type consisting of plastic wrap tubes or plastic cloth tubes. Non-porous diffusers include the nozzle, orifice, valve or shear type. These diffusers are generally constructed of metal or plastic components. They have larger openings and release larger bubbles than the porous type diffuser.

The location of the diffusers in an aeration tank are critical to the success of tank mixing and are critical to the energy required to introduce the air into the liquid. If the diffusers are located too high in the tank, poor mixing may result. If the diffusers are located unnecessarily deep, then excessive energy may be required to force the air into the water. The optimum solution for use of diffusers is to provide a balance between the energy requirements of mixing and oxygen transfer. Oxygen transfer is a direct function of the size of air bubbles coming from the diffuser and the distance the bubbles travel in the liquid. The alternate concern is that the finer the bubble from the diffuser, the more energy that is required to provide that bubble.

Typical locations of diffusers are approximately two feet off the bottom of a fifteen foot tank. When diffusers are located along one wall of a rectangular tank, a spiral flow mixing pattern develops in which the sewage is lifted up one side of the tank, rolls across the tank and down the other side. This mixing pattern has the potential of incurring a dead zone or an unmixed zone in the middle of the tank which may cause short circuiting of untreated sewage. Another type of diffuser pattern is called cross-role aeration. The diffusers are located across or at right angles to the path of flow of an aeration tank. This construction provides for good interaction between the sewage and the air bubbles but generally requires more structure for the support of the diffuser system than required in the spiral flow configuration.

The number of diffusers used in an aeration tank again depend on the two basic concerns of mixing and oxygen transfer. Basic design criteria call for a minimum quantity of air required to treat a pound of BOD. The specific equipment manufacturer can provide recommended air requirements per diffuser which can then be divided into the total design air requirements to obtain the number of diffusers needed. Typical ranges of air requirements per diffuser are from 4 to 15 CFM per diffuser. The exact range should be obtained from the equipment manufacturer. Since this is potentially a rather broad range, the operator has some flexibility to optimize his mixing requirements and air usage by varying the number of diffusers in the aeration tank.

There are a variety of diffusers on the marketplace. The following briefly describes some of the more common type diffusers found:

Porous Diffuser

The porous diffuser category includes ceramic and plastic porous tubes. The ceramic diffuser may be composed of materials such as aluminum oxide, bonded with high aluminum glass, or aluminum silocate grains ceramically bonded at high temperature. These diffusers are often cemented into recesses in the tank bottoms or clamped into metal holders. Their predominant feature is the generally long lifetime use before cleaning is required which have been reported to be from five to up to as much as twenty years.

A second porous diffuser is the plastic variety. One common type of diffuser in this category is the saran-wrap tube. In this diffuser, saran plastic cord is wrapped around a specially constructed frame. This plastic cord forms the diffusion media, and provides a uniform fine bubble with even distribution. Another feature of the plastic diffusers is their generally light weight which provides for ease of construction.

A third variation of porous diffusers is the use of a plastic sock-type media which is mounted on a fibreglass core or a rust resistant metal frame. These diffusers also provide for a fine bubble diffusion.

Non-porous Diffusers

Non-porous diffusers are of two general types, those using air only and those using air and water. Neither of these systems requires an elaborate air filtering system because the air discharged is through a much coarser medium. An example of the combination air and water unit is the water jet. Water is discharged through a nozzle with a high velocity through the injector. Air is introduced into the high velocity water stream which provides an excellent interface from air to water.

One category of the air only non-porous diffusers is a variety referred to as "spargers". These units were developed in the early 1950's. A unique turbulence develops as the concentrated airlift column above each sparger reacts with the surrounding mixed liquor. A short distance above the orifice the cluster of chain-like large air bubbles are broken into a cloud of small bubbles, thus providing good oxygen transfer. Spargers are usually mounted on headers at 12 to 24 inch centers. These units are relatively maintenance free as the larger openings and the pressure of the air keep particles from clogging the diffuser openings.

A third type of non-porous diffuser is a valve orifice diffuser. These units were first introduced in the late 1950's and generally work as a check valve might work. An example is the disk valve type diffuser where air is released around the disk from the annular opening between the disk and the flat rim. The air pressure in the header lifts the disk from its seat. When the air is shut off or a pressure drop occurs, the disk retreats and closes the space prohibiting mixed liquor to enter the air header.

As previously stated, there are many varieties of diffusers utilized but they all essentially utilize either a fine bubble or a coarse bubble configuration and the general distinction is the trade-off between the energy costs for producing the finer bubbles and the maintenance and upkeep of maintaining the fine bubble opening.

Pure Oxygen Aeration:

Pure oxygen used for providing dissolved oxygen in activated sludge plants has been applied on a more frequent basis the last few years. Pure oxygen can be applied to activated sludge with three different types of systems.

The first, and probably the most commonly used system, is to supply pure oxygen in a sealed enclosed reactor. In this environment tank pressure is maintained at greater than atmospheric pressure and oxygen is introduced into the tank. Mixing is provided by a separate aeration device either submerged turbines or surface aerators. The higher pressure and the pure oxygen environment provides for ideal conditions for oxygen transfer. Because oxygen transfer is so good in such an ideal environment, higher dissolved oxygen values can be found in this system than in conventional aeration systems. Because of this phenomena pure oxygen activated sludge systems are generally designed for higher F/M loadings. This characteristic then provides for an equivalent treatment plant to be constructed with smaller aeration tanks. A couple of the disadvantages of pure oxygen include the difficulties and the expense to generate pure oxygen and, secondly, the pure oxygen environment requires a higher degree of safety concern.

Another method of using pure oxygen is utilizing special type diffusers that provide pure oxygen to an open or conventional aeration tank. These diffusers range from the specially designed "Marax" diffuser which incorporates both diffusion and mixing in an open aeration tank to a "Norton Dome" type diffuser where pure oxygen is diffused through a granular material directly into the bottom of an aeration tank. Theoretically, either one of these systems could be used entirely as an oxygen supply for an open tank activated sludge system or they could be used to provide supplemental oxygen for highly loaded situations. Again, the concern with these systems is in the requirement of generating and handling pure oxygen. On the other hand, the major advantage of this kind of application is in its relatively efficient use of oxygen to supplement an existing overloaded system.

Clarifiers:

The clarification process in the activated sludge system is by far the most critical element for maintaining or violating effluent standards. The biological nature of activated sludge presents a very powerful system for the removal of organics from domestic wastewater. However, a major difficulty in the process stems from the problem of separating these biological solids from the water. Activated sludge has a density that is only slightly heavier than that of water and, therefore, sedimentation is difficult. The key to the success of sedimentation is the development of quality activated sludge floc. The floc is a conglomeration of many bacteria and other life forms in the activated sludge which collectively constitute a particle with density greater than any of the individual bacteria or other life forms. These floc when introduced into a quiescent zone will settle and separate from the sewage.

Final clarifiers generally are either rectangular or circular tanks.

Rectangular Clarifiers

The rectangular clarifiers physically separate the feed point to the clarifier from that of the effluent withdrawal. The mixed liquor is uniformally introduced to one end of the rectangular tank and travels down through the length of the tank where it is collected over weirs and discharged. The majority of the solids should settle at the front-end of the tank as the mixed liquor travels through the system. Scrapers, or some type of sludge collection system, gather the settled sludge and scrapes it to the head end of the tank where it is withdrawn through sludge hoppers and returned back to the aeration system. This operating mode is called "counter-current" because the liquid flows in one direction and the sludge flows in the other direction. One difficulty with rectangular clarifiers is in producing high water velocities at the discharge end of the tank. Since the weirs used to collect the effluent are generally located in a small portion of the clarifier, the average velocity through this section as compared to a velocity for the entire clarifier can be rather high.

One major advantage of rectangular clarifiers is in the economics of construction, especially when common walls can be used for multiple units.

Circular Clarifiers

Circular clarifiers, on the other hand, are generally more expensive to build but provide for a more uniform distribution of the liquid velocity around the clarifier and, therefore, provides a fairly ideal separation of the activated sludge from the sewage. In the case of circular clarifiers, return sludge is collected through draft tubes which are attached to a rake or scraper mechanism that revolves around the bottom of the clarifier. This mechanism utilizes the pressure exerted by the water column to force the sludge into open holes in collection pipes and then discharges this collected sludge into a hopper basket or a sludge pit at a lower elevation than the surface of the clarifier.

Various systems and designs are utilized to regulate and to control the discharge of return sludge from a clarifier. Basically, all these systems utilize pressure of the water surface and provide for some means to restrict or to increase openings from the various tubes that are used to withdraw the return sludge. In order to maintain a uniform collection of sludge from the bottom of the clarifier, it is necessary for an operator to balance these tubes to insure that an equal quantity of sludge is withdrawn from all portions of the clarifier.

Scum Collection:

Not all the material that passes through an activated sludge plant will settle in the clarifier. Frequently material will be generated which floats to the top of the clarifier. This material is referred to as "scum" and requires appropriate collection devices to prevent this material from escaping into the effluent. On rectangular clarifiers a scum baffle can be employed which intercepts the floating material before it reaches the weirs. It is then transferred to another part of the treatment system through the collection device. On circular clarifiers it is necessary to employ a sweep arm device which revolves around the clarifier and scrapes the floating material to a scum hopper. Again, this material is pumped to another part of the treatment plant for appropriate treatment and disposal.

Design Criteria:

Typical criteria used for final clarifiers in the activated sludge process employ an average surface overflow rate of 800 gallons per day per square foot of surface area. The velocity of the water going over weirs should be in the range of 10,000 to 30,000 gallons per day per linear foot of weir length. In many cases an operator needs to be more concerned with short-circuiting rather than just the average velocities. Factors such as non-level weirs, wind currents, improperly situated feed channels or withdrawal ports can induce short-circuiting in the clarifier. Any discrepancies found in the flow pattern in a clarifier can add significantly to the loss of solids from that unit. The sludge that is collected in the clarifier is returned to the aeration tank through a pumping system that is referred to as return sludge pumping. More detail of the operability of return sludge control will be addresssed later in this course. At this point, it is important to note that this pumping system must be regulated for each individual clarifier that is in operation. Any imbalance in the removal of sludge from the clarifiers will result directly in a build up and a discharge of solids from that clarifier.

Another feature of the activated sludge system is the requirement to waste the excess solids generated in the system. Again, wasting will be addressed later as a specific control problem. At this point, it is important to realize that the key to successful wasting is in the ability to waste a known quantity of material. This can be accomplished by wasting a portion of the return sludge or by providing separate sludge hoppers off the bottom of the clarifier and then wasting through a separate pumping system.

This brief overview of the activated sludge components has included the aeration tanks, aeration systems, clarifiers and sludge pumping systems. These units collectively comprise the system which is used in the majority of activated sludge secondary treatment plants in this country.

Lesson 2: Activated Sludge Variations & Modes

Through the many years of use, the activated sludge process has been modified and adapted to meet many situations. It is important to remember, however, that no matter what variation or name is used the process is basically the same and they should all be able to produce a high quality effluent. In Lesson 1, we defined the basic elements of operation as (1) waste sludge control, (2) return sludge control, and (3) dissolved oxygen control. The task in operations is to control and optimize these needs for any specific plant. In order to do that, it helps to understand a little more about the process modifications that may be faced. These modifications can be broken down into two groups which are called Process Variations and Process Modes.

Process Variations:

Process variations are historically defined by the three major process variables of:

(1) Aeration detention time (DT)
(2) Mixed liquor suspended solids (MLSS)
(3) Ratio of BOD_5 loading to MLSS (F/M)

There are four classical variations which are frequently encountered by an operator. These are:

(1) High rate
(2) Conventional
(3) Contact stabilization
(4) Extended aeration

High Rate:

The high rate system (Figure 1) takes advantage of the settleability of sludge when the treatment system is loaded at a fairly high rate. Generally, the level of treatment which results is somewhat comparable to

DETENTION TIME	2 HR
LOADING	100# BOD/1,000 FT^3
F/M	1.0 #BOD/#MLUSS (OR GREATER)
AIR FLOW	1500 FT^3/ LB BOD

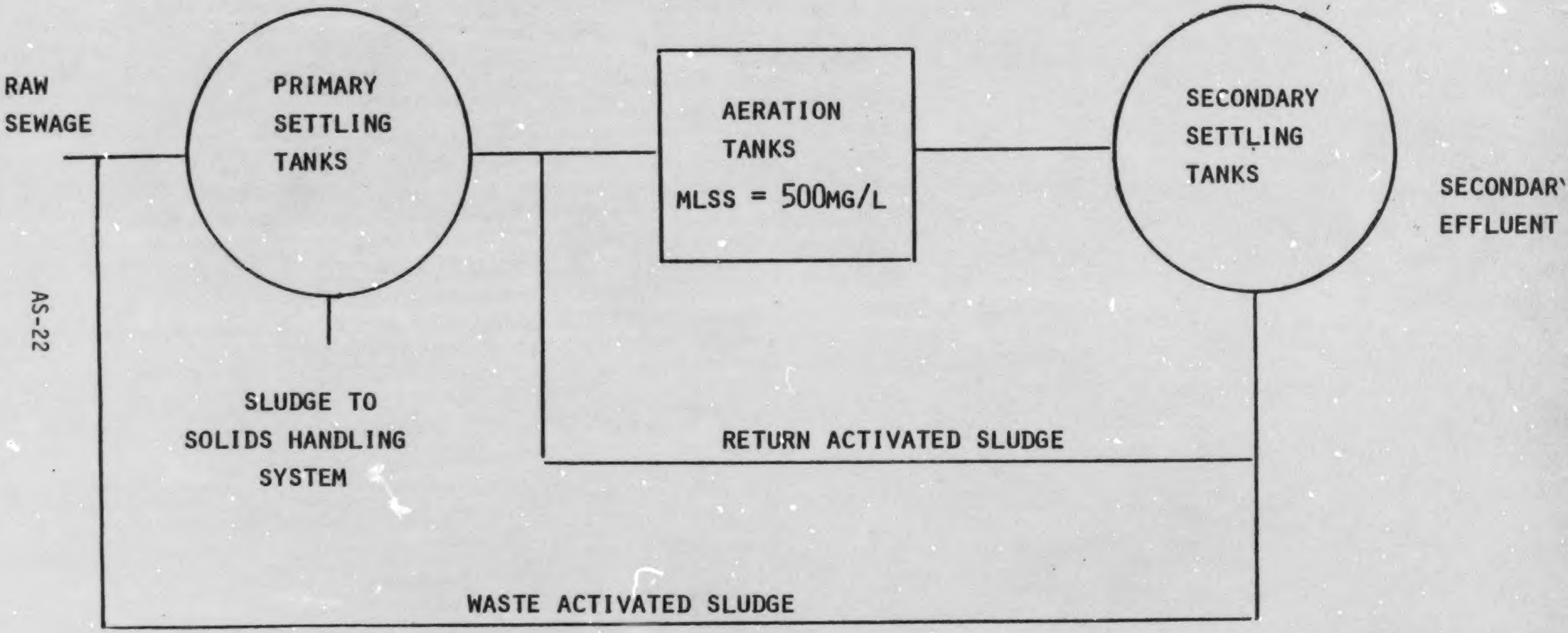

RAW
SEWAGE
PRIMARY
SETTLING
TANKS
AERATION
TANKS
MLSS = 500MG/L
SECONDARY
SETTLING
TANKS
SECONDAR
EFFLUENT
SLUDGE TO
SOLIDS HANDLING
SYSTEM
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

FIGURE 1. HIGH RATE ACTIVATED SLUDGE PROCESS

a typical high-rate trickling filter plant but process control risks are much higher. When ideal conditions are present a high quality effluent may be able to be maintained. Although the process can be applied effectively in certain situations, a large, 300 MGD plant has abandoned this process, choosing to treat only about one-third of their flow at conventional loading levels. Apparently the quality of the combined effluents consisting of 100 MGD treated by conventional activated sludge and 200 MGD treated with primary sedimentation only is as good or better than the quality when the entire flow was treated by the high rate process.

Conventional Rate:

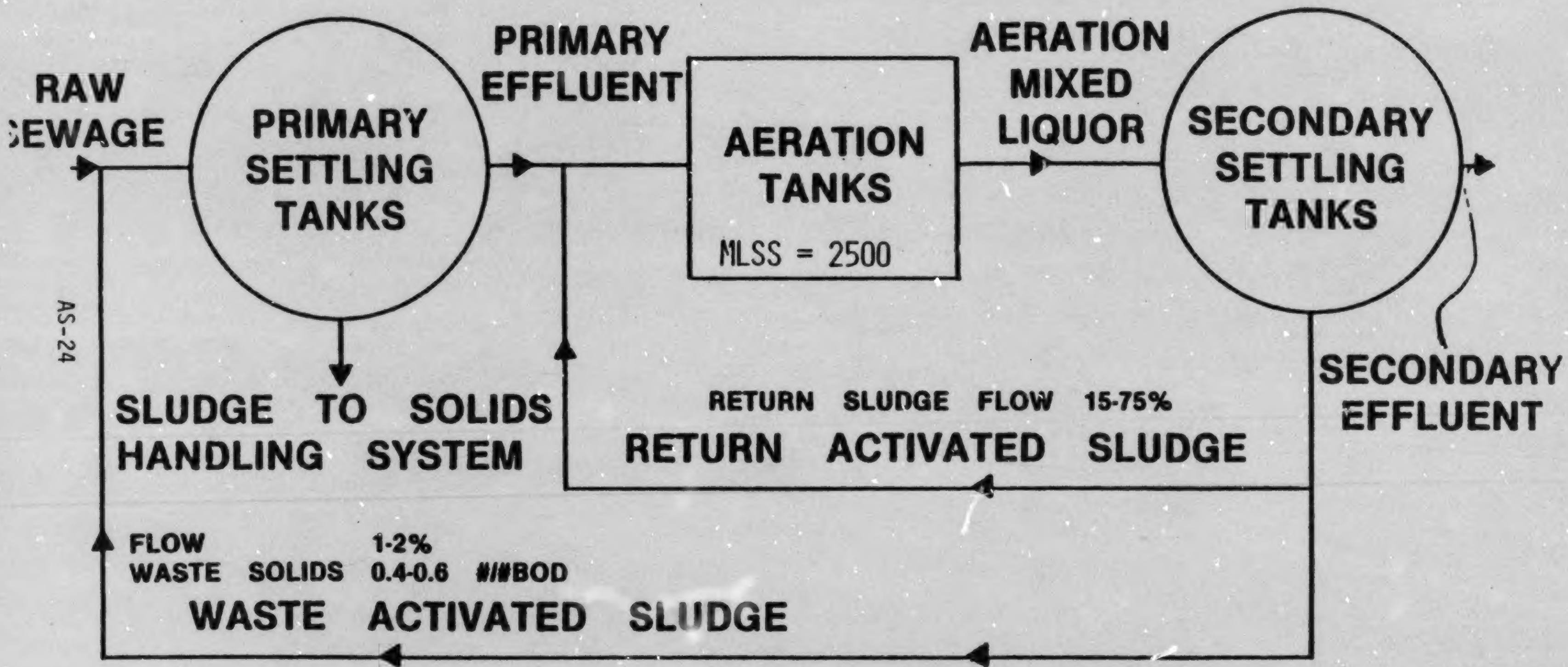
For a typical domestic wastewater at about 20 degrees Celcius, the conventional process (Figure 2) operates between MCRT values of 5 to 15 days and F/M ratios of 0.2 to 0.5 lbs BOD applied/lb MLVSS/day. Most large municipal treatment plants operate in the conventional activated sludge zone. Plants operating in the middle of this range produce an excellent effluent quality and do not nitrify. At the lower end of this loading range, an even better effluent is sometimes produced although problems sometimes occur when the plant slips slightly or goes completely into nitrification. This often results in operational problems such as rising sludge in the clarifiers, the appearance of filaments in the sludge, and the formation of a brown, greasy-appearing foam. Filamentous growths and poor sludge settleability have been associated with the conventional process at the upper end of this loading range. Dispersed growth and a cloudy effluent are also quite common. Usually the operator can see this sort of condition by plotting a trend of the organic loading in his treatment process (either the F/M ratio or the actual MCRT). Other signs of a more physical nature may also be used by the operator to evaluate an "overloaded" condition. For example, once high loading levels are reached, a stiff, white detergent-type foam is often observed on the aeration tanks.

Contact Stabilization Rate:

The contact stabilization (Figure 3) rate is not a very well defined mode. It actually represents a variety of situations which cannot be defined as either conventional or extended aeration. Yet, there is such

DETENTION TIME 4-8 HR.
LOADING 30-40 #BOD/1,000 FT^3
F/M 0.2-0.5 #BOD/#MLVSS
AIR 750-1,000 FT^3/#BOD
SLUDGE AGE 4-6 DAYS

OVERFLOW RATE 800-1,000 GPD/FT^2
DETENTION TIME 1-3 HR.



RAW SEWAGE

PRIMARY SETTLING TANKS

PRIMARY EFFLUENT

AERATION TANKS

MLSS = 2500

AERATION MIXED LIQUOR

SECONDARY SETTLING TANKS

SECONDARY EFFLUENT

SLUDGE TO SOLIDS HANDLING SYSTEM

RETURN SLUDGE FLOW 15-75%

RETURN ACTIVATED SLUDGE

FLOW 1-2%
WASTE SOLIDS 0.4-0.6 #/#BOD

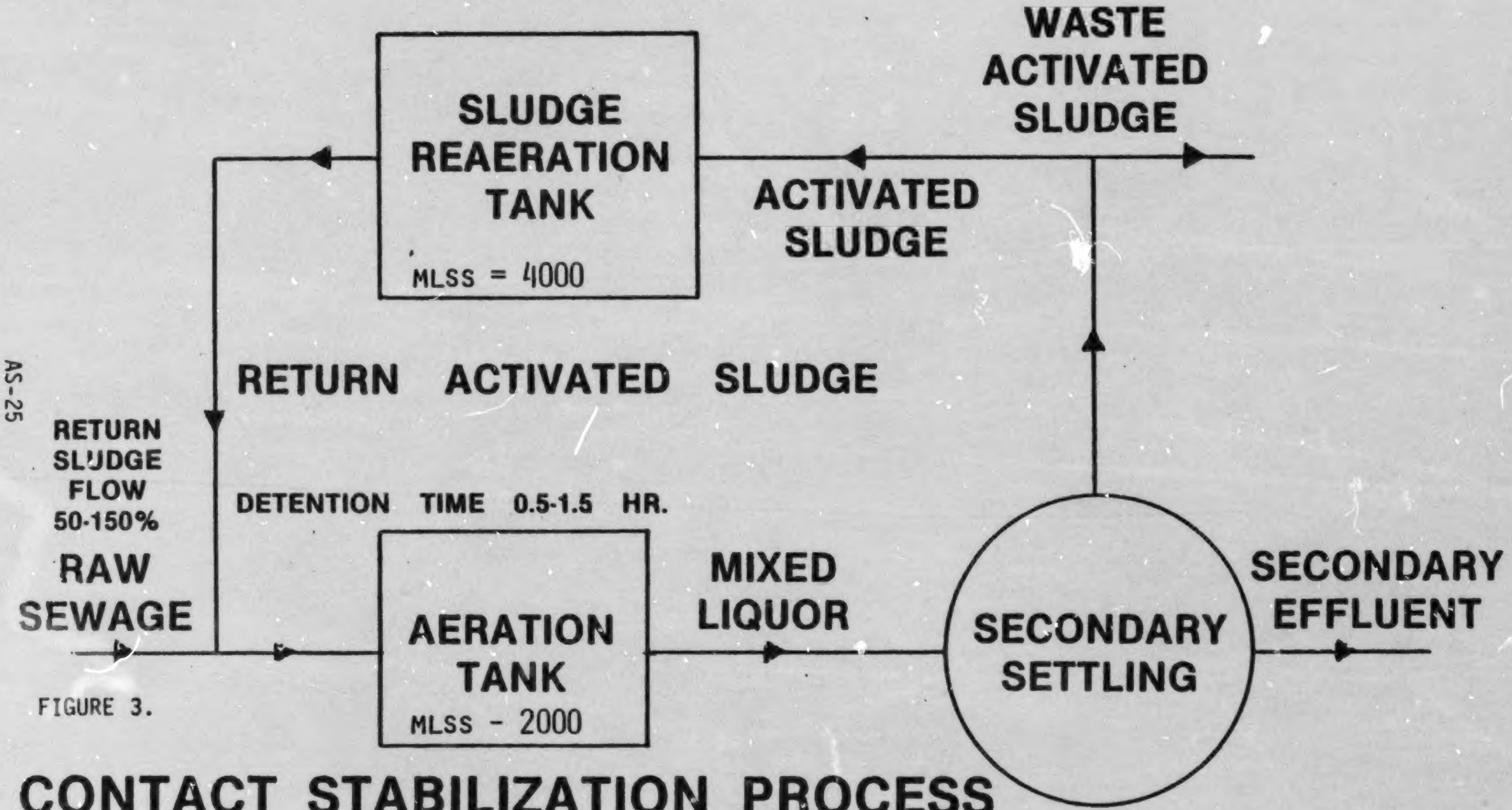
WASTE ACTIVATED SLUDGE

AS-24

CONVENTIONAL ACTIVATED SLUDGE PROCESS

FIGURE 2.

DETENTION TIME	4-8 HR.
LOADING	35-70 #BOD/1,000 FT^3 (COMBINED VOLUME)
F/M	0.2-0.5 #BOD/#MLVSS (CONTACT TANK)
AIR FLOW	750-1,500 FT^3/#BOD


WASTE ACTIVATED SLUDGE

SLUDGE REAERATION TANK

MLSS = 4000

ACTIVATED SLUDGE

RETURN ACTIVATED SLUDGE

RETURN SLUDGE FLOW 50-150%

DETENTION TIME 0.5-1.5 HR.

RAW SEWAGE

AERATION TANK

MLSS - 2000

MIXED LIQUOR

SECONDARY SETTLING

SECONDARY EFFLUENT

AS-25

FIGURE 3.

CONTACT STABILIZATION PROCESS

a process and it does work. Physically the process is defined as one with two aeration areas on tanks; one for treating sewage and one for conditioning the activated sludge. The physical relationships are not nearly as important as are the actual loading considerations. The loading factors mean that a system only half the size of the extended aeration plant can be installed with only a slight increase in solids production and operator attention.

It is also possible that this same loading rate includes the nitrification range of the conventional modes. This is important to the operator because there may be a range of poor settleability between the conventional and contact stabilization modes.

The contact stabilization arrangement can also be used as a means to adjust a conventionally loaded plant to handle shock loads of both organic and toxic substances. These cases are more of a survival attempt rather than a long term stable solution.

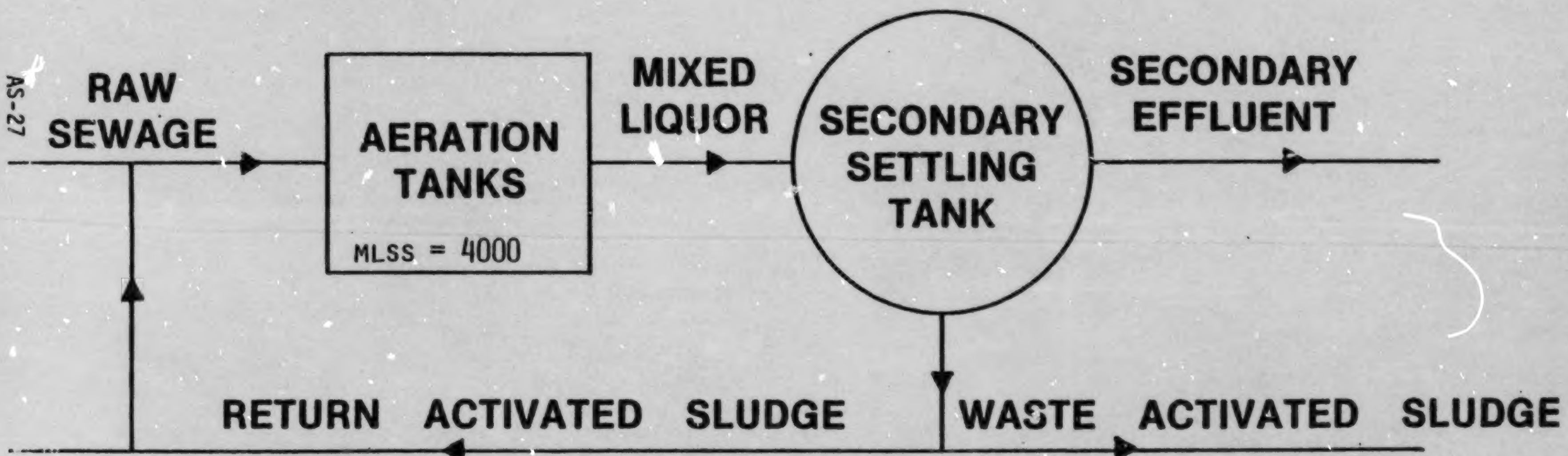
Extended Aeration Rate:

The lowest range of process loading where successful operation may be accomplished is the extended aeration range (Figure 4). Generally plants operating in this range are small in size and do not receive 24-hour supervision. Such plants are very conservative in design and generally operate with an MCRT of 20-40 days and F/M ratio of 0.05 to 0.15 lbs BOD applied/lb MLVSS/day, based on typical domestic wastewater at a temperature of 20° C. The extended aeration process is sometimes referred to as the "total oxidation process." This name is derived from the fact that these plants are designed with such low loadings that the simple kinetics theory used to describe processes of higher loading would predict that all of the influent BOD will be converted to CO_2. This is why some manufacturers claim that no wasting is necessary for their extended aeration designs. In actual fact, there is no such thing as the "Total Oxidation Process" and even after extremely long periods of aeration, suspended volatile matter remain in the effluent. Although sludge wasting need not be conducted on a daily basis in plants operating in the extended aeration range, occasional wasting is an absolute necessity to maintain steady performance.

Often the effluent of the extended aeration processes contains small pinpoint floc which may be observed passing over the weirs of the secondary

DETENTION TIME 16-24 HR.
LOADING 10-15 #BOD/1,000 FT^3
F/M 0.01-0.08 #BOD/#MLVSS
AIR FLOW 2,000-2,500 FT^3/#BOD

OVERFLOW RATE 300-600 GPD/FT^2



AS-27

RAW SEWAGE

AERATION TANKS

MLSS = 4000

MIXED LIQUOR

SECONDARY SETTLING TANK

SECONDARY EFFLUENT

RETURN ACTIVATED SLUDGE

WASTE ACTIVATED SLUDGE

RETURN SLUDGE FLOW 50-200%

WASTE SOLIDS 0.1-0.2 #/#BOD

EXTENDED AERATION PROCESS

FIGURE 4.

clarifier. When the loading in an extended aeration plant is in the higher portion of the loading range, a number of operating problems may occur. Because the entire extended aeration range is in the nitrification zone, denitrification and rising sludge problems may result. Also the same brown, greasy foam, filaments, and poor settleability mentioned in discussion of the conventional process at low loading may occur under these circumstances. If possible, these problems may be improved by using less aeration capacity or decreasing the level of MLSS.

Other problems associated with the extended aeration process have to do with the fact that some sludge must be wasted and that many operators have been told that wasting is not necessary. Indeed, many small extended aeration plants have no facilities installed to make wasting possible. Under these circumstances, it is not uncommon for sludge to creep over the clarifier weirs whenever fluctuations in flow occur. Unfortunately, this results in a significant reduction in removal efficiency and can lead to process instability.

If the operator of an extended aeration plant frequently experiences losses of solids over the effluent weirs, there are two remedies which can be used: regular sludge wasting, and flow equalization. Of the two, sludge wasting is by far the most important. A conscientious operator should keep track of the solids intentionally wasted and the solids that go over the effluent weirs. In this manner, the plant can be operated to achieve a steady inventory of biomass.

If plant design provisions have not been made for sludge wasting, the operator should attempt to improvise some sort of temporary or permanent method. Depending on the specific design of the plant and the geography and environmental conditions around it, the operator may be able to arrange for constructing sludge beds or lagoons for wasting facilities. The sludge from plants of this sort is generally already "aerobically" digested. If it is placed directly on a sand bed for drying, or in a lagoon, it will generally not have a foul odor.

Even when regular wasting is carried out, a high degree of flow variation in extended aeration plants will often cause solids losses. This is probably due to the particular characteristics of the floc produced in the low loading range as well as to the flow variations themselves. In some cases, if the aeration tank is large enough, the operator can design a makeshift system which will allow the use of the aeration tank as a flow equalization device. Minor modifications of this sort will go a long way to improve suspended solids removal in plants where losses are primarily due to hydraulic fluctuations.

Loading Factor:

One way to help evaluate any specific plant is to look at a factor which accounts for the three major process variables. Therefore we can define:

$$\text{Loading Factor (LF)} = \frac{\text{DT X MLSS}}{\text{F/M X 1000}}$$

Example #1: Consider a high rate plant -

Where: DT = 2 hrs.
MLSS = 500 mg/l
F/M = 1.0

$$\text{LF} = \frac{2 \text{ X } 5000}{1 \text{ X } 1000}$$

$$= 1$$

Example #2: Consider plant with no primary clarifier -

Where: DT = 10 hrs.
MLSS = 2500
F/M = 0.2

$$\text{LF} = \frac{10 \text{ X } 2500}{0.2 \text{ X } 1000}$$

$$= 125$$

Many people would call example #2 an extended aeration plant just because there is no primary clarifier, when in practice that facility operates more like a contact stabilization plant.

Table 1 shows the calculation of LF for four typical variations and compares these to typical sludge yields. Sludge yield, which is the observed or measured pounds of solids produced per pound of BOD fed into the system, is important because it translates into wasting requirements. Table 2 relates the impact of the four variations to a typical waste requirement and Figure 5 graphs the anticipated waste requirements as a function of the loading factor. More specific control analyses are required for day-to-day operation and are discussed later.

Loading Modes:

After the specific process variation has been determined for a facility the next information needed is the specific mode to be used or is available for use. Modes offered for the activated sludge process are almost as variable as there are treatment plants. Specifically, modes are any set of specific physical changes in the system which enhance one or more of the basic control requirements. Complete mix mode is probably one of the most commonly used. This mode provides a very uniform environment because, theoretically, all conditions are the same in all places in the aeration tank. As long as there is no change in the loading variation as just discussed, there will be no substantial change in requirements for wasting return rates or D.O. The following are brief outlines of six activated sludge modes found in many areas.

Complete Mix (Figure 6)

- Contents of tank are uniformly mixed by tank shape, location of aerators and feed points
- Uniformity means same D.O. and same MLSS in all places
- Best understood by researchers
- Stable because shock loads are diluted

Plug Flow (Figure 7)

- Wastewater and RAS flow through plant in uniform slug
- Generally long narrow tanks are used or baffled in rectangular tanks

TABLE 1. TYPICAL SLUDGE YIELDS

AERATION VARIATIONS	T HRS.	MLSS MG/L	F/M LB BOD/LB MLSS	LOADING FACTOR	Y LBS WAS/LB BOD
EXTENDED	24	4000	.01 - .08	1000	.2
CONTACT*	.5/4-8	2000/4000	.2	125	.3
CONVENT-IONAL	6-8	2500	.5	35	.5
HIGH RATE	2	500	1.0	1	1.0

*INCLUDES BOTH CONTACT AND REAERATION TANKS.

WHERE: T = HRS. = HYDRAULIC DETENTION TIME IN AERATION TA

MLSS = MG/L = MIXED LIQUOR SUSPENDED SOLIDS

$F/M = \frac{\text{LB BOD}}{\text{LB MLSS}}$ = FOOD TO MICROORGANISM RATIO

$Y_{obs} = \frac{\text{LBS WAS}}{\text{LBS BOD}}$ = SOLIDS PRODUCTION

TABLE 2 TYPICAL$_{(1)}$ WAS GOALS FROM F/M AND MCRT DATA

AERATION VARIATIONS	YOBS LBS. WAS/LB. BOD	WASTE GOALS LBS. WAS
EXTENDED	.2	250
CONTACT$_{(2)}$	.3	375
CONVENTIONAL	.5	625
HIGH RATE	1.0	1.250

(1) 1 MGD PLANT

P.E. BOD = 150 MG/L

(2) INCLUDES BOTH CONTACT AND REAERATION TANKS

$$\frac{1}{MCRT} = YOBS \times F/M$$

WHERE: MCRT = SOLIDS RESIDENCE TIME IN SYSTEM

F/M = FOOD TO MICROORGANISM RATIO EXPRESSED AS LBS. BOD FEED/LB MLSS

YOBS = SOLIDS PRODUCTION EXPRESSED AS LBS. WAS/LBS BOD FEED

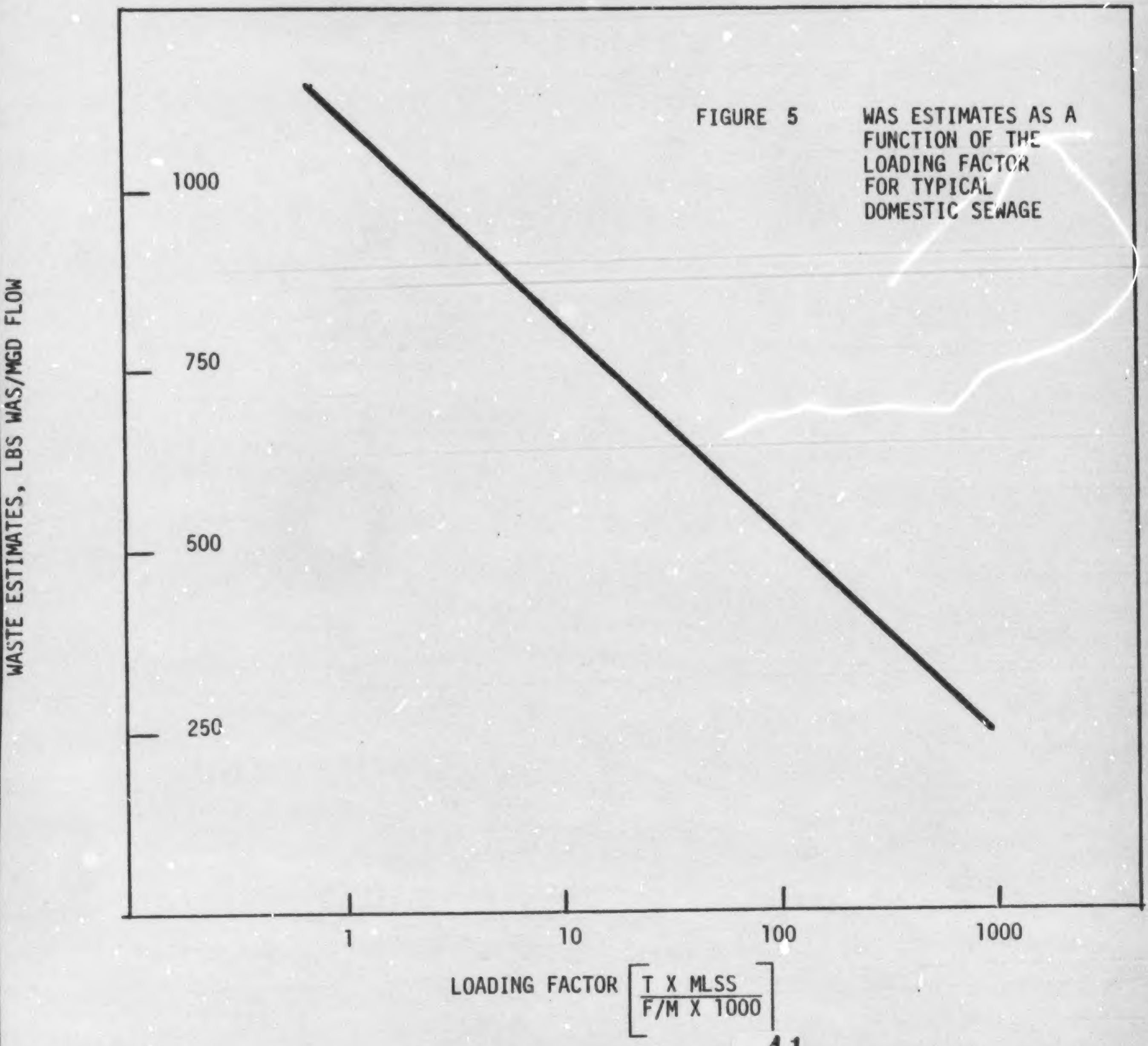


FIGURE 5 WAS ESTIMATES AS A FUNCTION OF THE LOADING FACTOR FOR TYPICAL DOMESTIC SEWAGE

- Considered to produce good settling floc
- Very stable operation for conventional loads

Step Aeration (Figure 8)

- To avoid overload of sewage at head end of tank, raw sewage can be added stepwise in a rectangular tank
- Usual increments are 3 to 4
- If first increment is skipped then return sludge can be regenerated

Tapered Aeration (Figure 9)

- In a rectangular tank oxygen requirements diminish as treatment progresses
- Reduce air discharge to points down stream in tank by:
    1) Porportioning diffusers according to air demands
    2) Valve air headers according to air demands
    3) Porportion use of mechanical aerators

Kraus Process (Figure 10)

- High strength wastes have been historically related to sludge bulking
- Kraus studied the use of aerobically conditioning digester overflow liquor
- Recent reports have indicated digester supernatant is toxic to filamentous organisms
- Stabilization tank operates under high degree of nitrification

ABF (Figure 11)

- Uses both fixed - film and suspended growth
- Fixed film utilize low power and stability of trickling filter process

- Suspended growth provides the performance and controllability of the activated sludge process
- Can operate under very high organic loadings

Aeration Performance

A great deal can be learned about the operation of an activated sludge process by reviewing aeration requirements and performance. Basically, the mixed liquor is a suspension of microorganisms that consume the organic matter in the wastewater while utilizing dissolved oxygen and releasing carbon dioxide to produce new cells.

The air requirement is dependent upon the oxygen transfer rate to the mixed liquor and the utilization of the dissolved oxygen by the microorganisms. The oxygen transfer rate is chiefly dependent on the design of the aeration system. The rate of dissolved oxygen utilization is dependent upon the microorganism activity as they react to organic loading, pH, temperature, aeration period and availability of dissolved oxygen. The air requirements may be based on more than one parameter. The most frequently used parameters by operators include the amount of air applied per pound COD or BOD removed (CF air/lb removed) in the process and the amount of air applied per gallon of wastewater treated (CF air/gal). Typical aeration rates for these parameters are presented in Table 3.

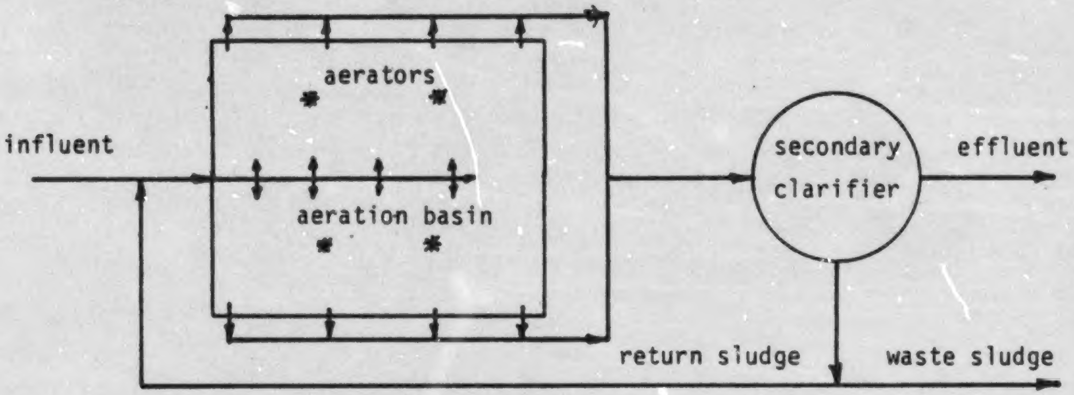

aerators
influent
aeration basin
secondary clarifier
effluent
return sludge
waste sludge

FIGURE 6
COMPLETE MIX

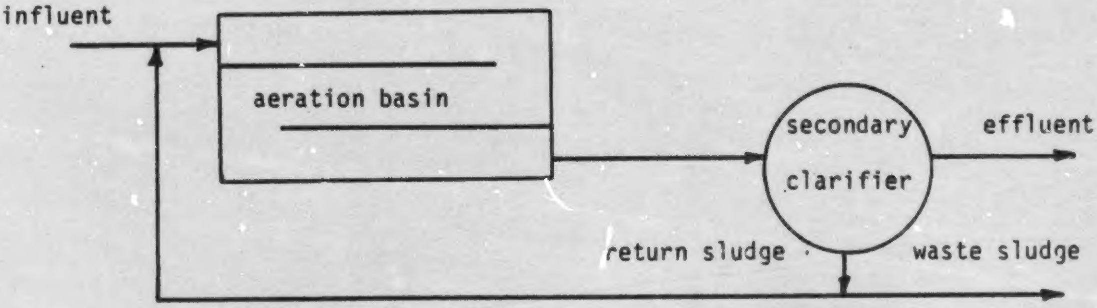

influent
aeration basin
secondary clarifier
effluent
return sludge
waste sludge

FIGURE 7
PLUG FLOW

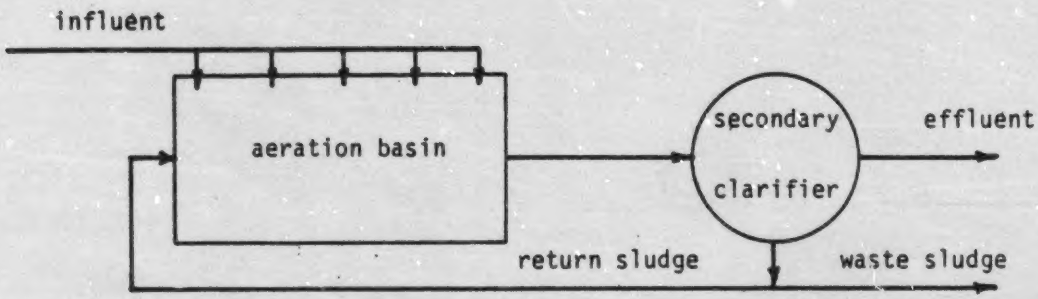

influent
aeration basin
secondary
clarifier
effluent
return sludge
waste sludge

FIGURE 8
STEP AERATION

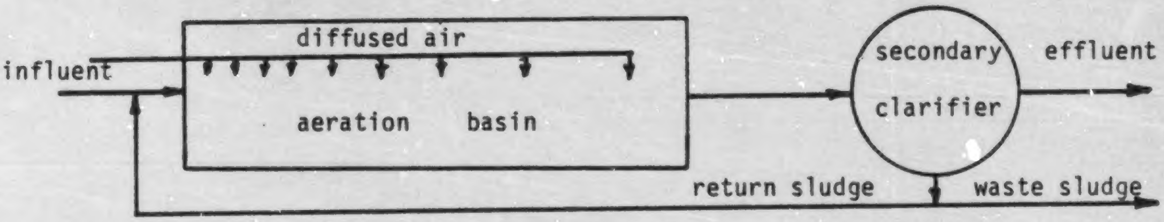

diffused air
influent
aeration basin
secondary
clarifier
effluent
return sludge
waste sludge

FIGURE 9
TAPERED AERATION

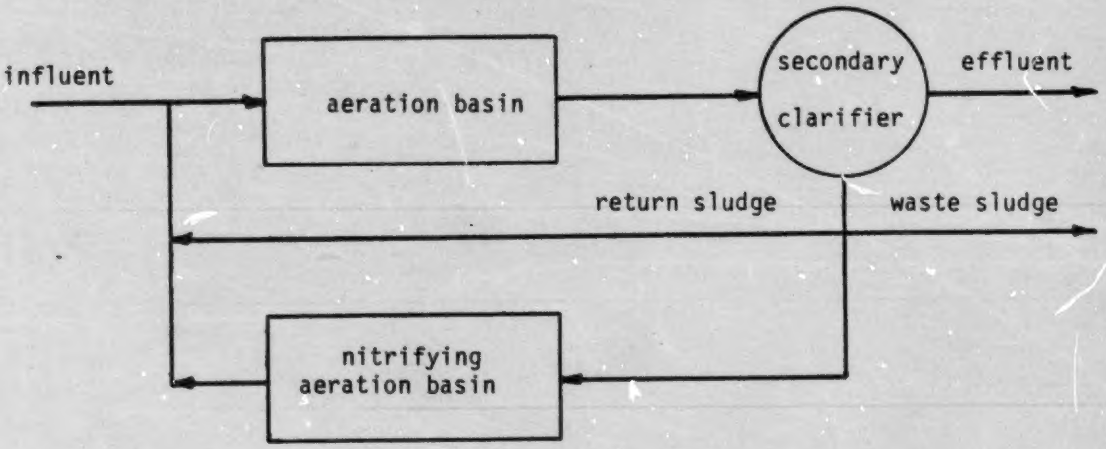

influent
aeration basin
secondary clarifier
effluent
return sludge
waste sludge
nitrifying aeration basin

FIGURE 10
KRAUS PROCESS

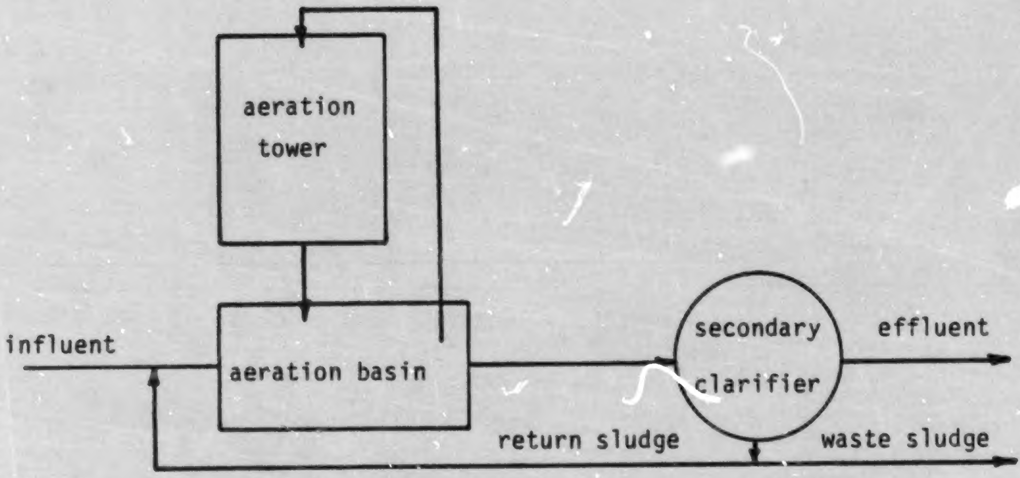

aeration tower
influent
aeration basin
secondary clarifier
effluent
return sludge
waste sludge

FIGURE 11
ACTIVATED BIOFILTER
(ABF)

TABLE 3.

TYPICAL AIR REQUIREMENT PARAMETERS (1)

Diffused Aeration System			Mechanical Aeration System System	
CF Air/lb Removed		CF Air/Gal	lbs O_2 lbs Removed	
COD	BOD		COD	BOD
1000 - 2000	800 - 1500	0.5 - 3.0	1.5 - 1.8	1.0 - 1.2

Aeration requirements change when process is nitrifying.

When evaluating aeration requirements, remember that the 5-day BOD, and the COD only reflect the carbonaceous portion of the organic loading and not the nitrogenous portion of the organic loading. The aeration requirements will be affected by the degree of nitrification as it relates to the nitrogenous strength of the organic loading as well as by the wastewater temperature and pH.

The aeration performance parameters can be determined as follows:

How to calculate CF Air/lb removed.

Example Calculation

A. Data Required
   1. COD or BOD removed, lbs/day = 22,000 BOD
   2. Total Air applied, CF/day = 31,900,000

B. Determine CF air/lb COD or BOD removed.

$$\text{CF Air/lb removed} = \frac{\text{Total air applied}}{\text{BOD, lbs/day}}$$

$$= \frac{31{,}900{,}000}{22{,}000}$$

$$= 1450$$

How to calculate CF Air/gal

Example Calculation

A. Data Required:
   1. Total air applied, CF/day = 31,900,000
   2. Total influent flow/day to aeration tank, gpd = 13,000,000 (exclude RAS flow rate)

B. Determine CF air/gal wastewater treated

$$\text{CF air/gal} = \frac{\text{Total air applied}}{\text{Total flow, gpd}}$$

$$= \frac{31{,}900{,}000}{13{,}000{,}000}$$

$$= 2.4$$

---

(1) Process control manual for aerobic biological wastewater treatment facilities, EPA - 430/9-77-006

ACTIVATED SLUDGE

Lesson 3: Biological Nature of Activated Sludge

The biological nature of activated sludge is the most critical concept for understanding activated sludge operation. As obvious as this statement may sound today, it took scientists considerable time to understand that activated sludge is a collection of living organisms and not just sewage solids.

Sludge Quality:

As stated in Lesson 1, the "Goal" of Activated Sludge Control is to economically produce a high quality effluent. To this end, the activated sludge biomass needs to utilize the organic material in sewage in an efficient manner and it must also exhibit the ability for efficient separation of biological solids from the water. The achievement of these two objectives provides a basic definition of Sludge Quality. Stated another way, good sludge quality is when the biomass settles rapidly in the final clarifier and produces an effluent that is low in BOD and TSS.

Before we can monitor and control sludge quality, it is helpful to understand what we're really talking about. Activated sludge or biomass is a mixture of microorganisms which contacts, accumulates and digests biodegradable material from wastewater. This mixture of microorganisms includes viruses, algae, bacteria, protozoa, fungi and worms; but the two most important ones are bacteria and certain protozoa. An additional important factor is that this mixture must somehow stick together in clumps called floc in order to separate from the water. Good Sludge Quality can now be further defined as a biomass that has the right mixture of bacteria and protozoa and has the ability to form flocs.

Bacteria:

Bacteria are ideally suited for consuming dissolved organic materials and small, undissolved particles of organic materials. Bacteria are microscopic organisms which make up the major portion of activated sludge. A bacterium is a single cell, capable of sustaining life, and is made up of the cell wall which holds the cell together; the cytoplasmic membrane which holds the protoplasm within the cell and which is permeable for transport of nutrients and waste products; protoplasm, living cell material; and a nucleus which is like the brain of the organism.

These single celled organisms grow in the wastewater by consuming biodegradable materials. The biodegradable materials contained in wastewater are proteins, carbohydrates, fats and many other compounds. The process can be described by the following general biochemical equation:

$$\text{Food} + O_2 + \text{Bacteria} \longrightarrow CO_2 + H_2O + NH_3 + \text{Energy} + \text{New bacterial cells.}$$

Just like us, bacteria have to eat to live, but they eat differently than humans do. When we eat, we take food into our bodies. Bacteria do the same by two processes: adsorption and absorption. In the first process, adsorption (Figure 1), particles of food or dissolved nutrients and the bacterium adhere or stick to each other. The bacterium secretes enzymes which dissolve food particles into very small units which then can pass through the bacterium's cell membrane. This process is called exocellular digestion (Figure 2). The bacterium absorbs these dissolved materials through the cell wall and cytoplasmia membrane into the cell. This completes the eating process.

After eating, the bacterium internally digests absorbed materials by further breaking down the nutrients into smaller units for energy production or putting the smaller units back together in forms required by the bacteria for growth. All of these biochemical reactions are brought about by enzymes.

Oxidation Pressure:

Let's return for a minute to how bacteria grow. In activated sludge, nutrients in the cell are oxidized to produce growth and energy. The oxidation process is called respiration. In activated sludge respiration is used to produce energy for both growth and cell maintenance. Cell growth is accomplished through assimilative respiration. This means that some nutrients which have entered the cell are broken down to produce energy. This energy is used to put together other nutrients to form protoplasm (living cell material). The energy required for this is supplied from assimilative respiration. But a cell has to produce energy to maintain

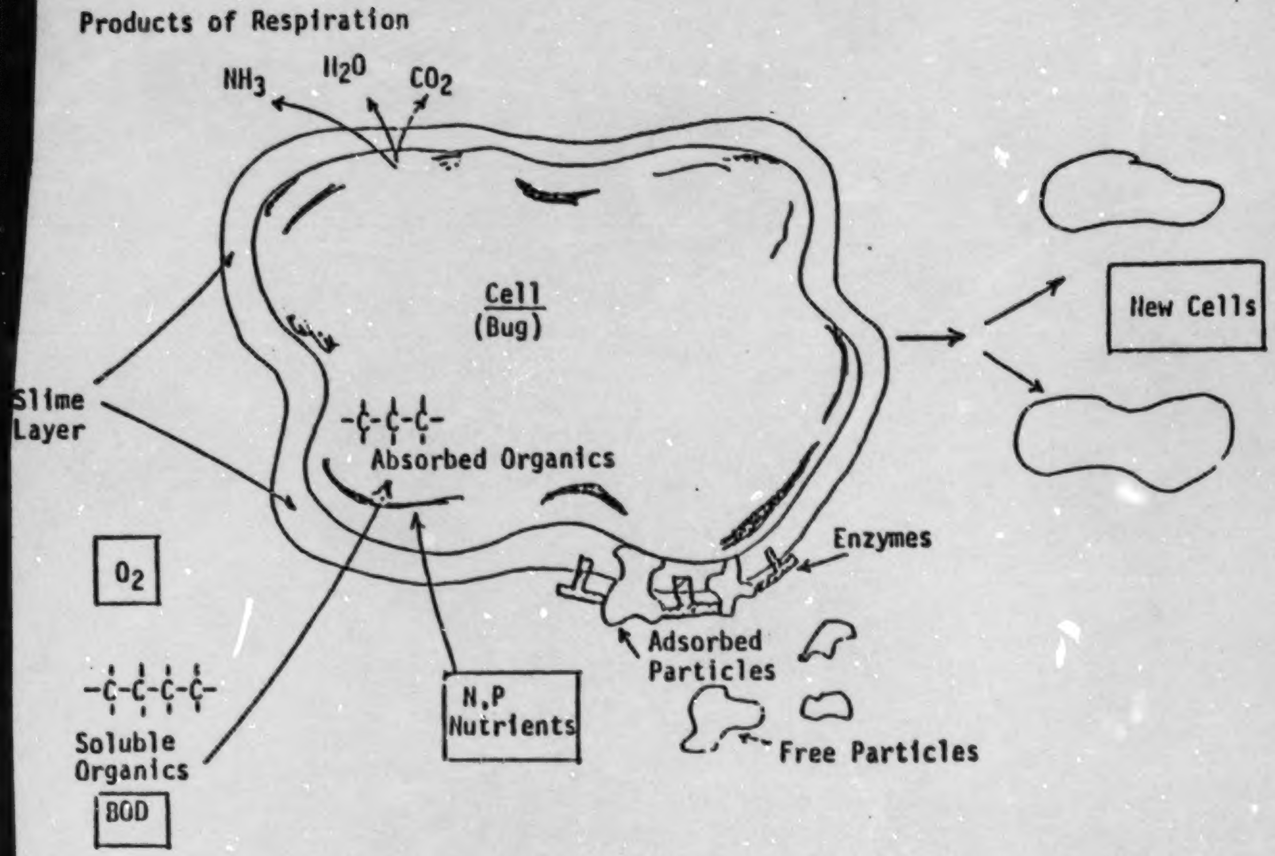
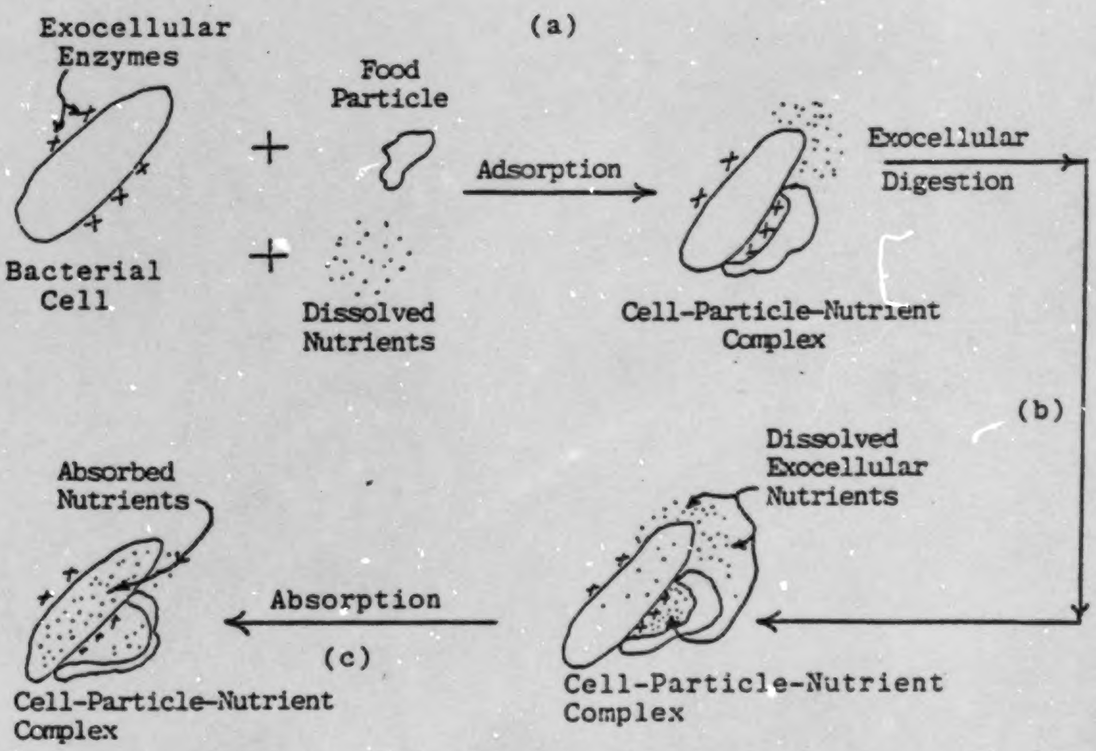

Products of Respiration
NH_3
H_2O
CO_2
Cell (Bug)
New Cells
Slime Layer
Absorbed Organics
Enzymes
O_2
Adsorbed Particles
Soluble Organics
BOD
N,P Nutrients
Free Particles

FIGURE 1. BACTERIA LIFE CYCLE



(a)
Exocellular Enzymes
Food Particle
Bacterial Cell
Dissolved Nutrients
Adsorption
Cell-Particle-Nutrient Complex
Exocellular Digestion
(b)
Dissolved Exocellular Nutrients
Absorbed Nutrients
Absorption
(c)
Cell-Particle-Nutrient Complex
Cell-Particle-Nutrient Complex

FIGURE 2. ADSORPTION, EXOCELLULAR DIGESTION AND ABSORPTION

itself as well as to grow. The respiration for cell maintenance energy production involves breaking down new or stored nutrients and is called endogenous respiration - a term with which you are all familiar. A bacterial cell is undergoing both assimilative and endogenous respiration at the same time, all of the time, but to different degrees depending upon available food supply.

If a cell has plenty of food available, it is growing and assimilative respiration and solids production predominate. If there is little or no food and if it is not growing or growing very slowly, then endogenous respiration predominates. Being able to control activated sludge means controlling the relationship between assimilative and endogenous respiration and solids production. In other words, controlling the amount of food available to a bacteria while providing a proper respiration environment is a definite part of activated sludge control and we call the impact of food Oxidation Pressure because food (BOD) exerts pressure on the activated sludge system.

Higher Life Forms:

The higher life forms in activated sludge are ideally suited for eating and digesting undissolved particles of organic materials including bacteria. Protozoa are the most common of these organisms. Protozoa are all single celled organisms like bacteria but they are hundreds of times larger. Their size makes them easily recognizable under a microscope and thus offers a potentially easily identified indicator of sludge quality. Protozoa are strictly aerobic and like bacteria, some can be harmful to man if ingested. Protozoa come in all kinds of shapes but they all eat and move about with similar characteristics. Usually there is some kind of oral cavity (mouth) used to catch or lodge food particles. When the food particles are ingested, they can be stored in compartments called vacuoles. Enzymes then break down the food so it can be absorbed through the cell walls. Protozoa all exhibit locomotion, usually with hair-like appendages or through actual movement of the body. Protozoa are classified by their type of locomotion. The four most common groups found in activated sludge include: amoeba, ciliates, flagellates, and suctoria.

One other fairly common type of higher life form is a rotifer. Rotifers are aerobic and multi-cellular organisms that are efficient grazers of bacteria, small flocs or particles of food. They have cilia around their mouth which helps them feel. Rotifers are probably the most complex higher life forms common to activated sludge and are thus associated with an over stabilized (aerobically-digested) sludge.

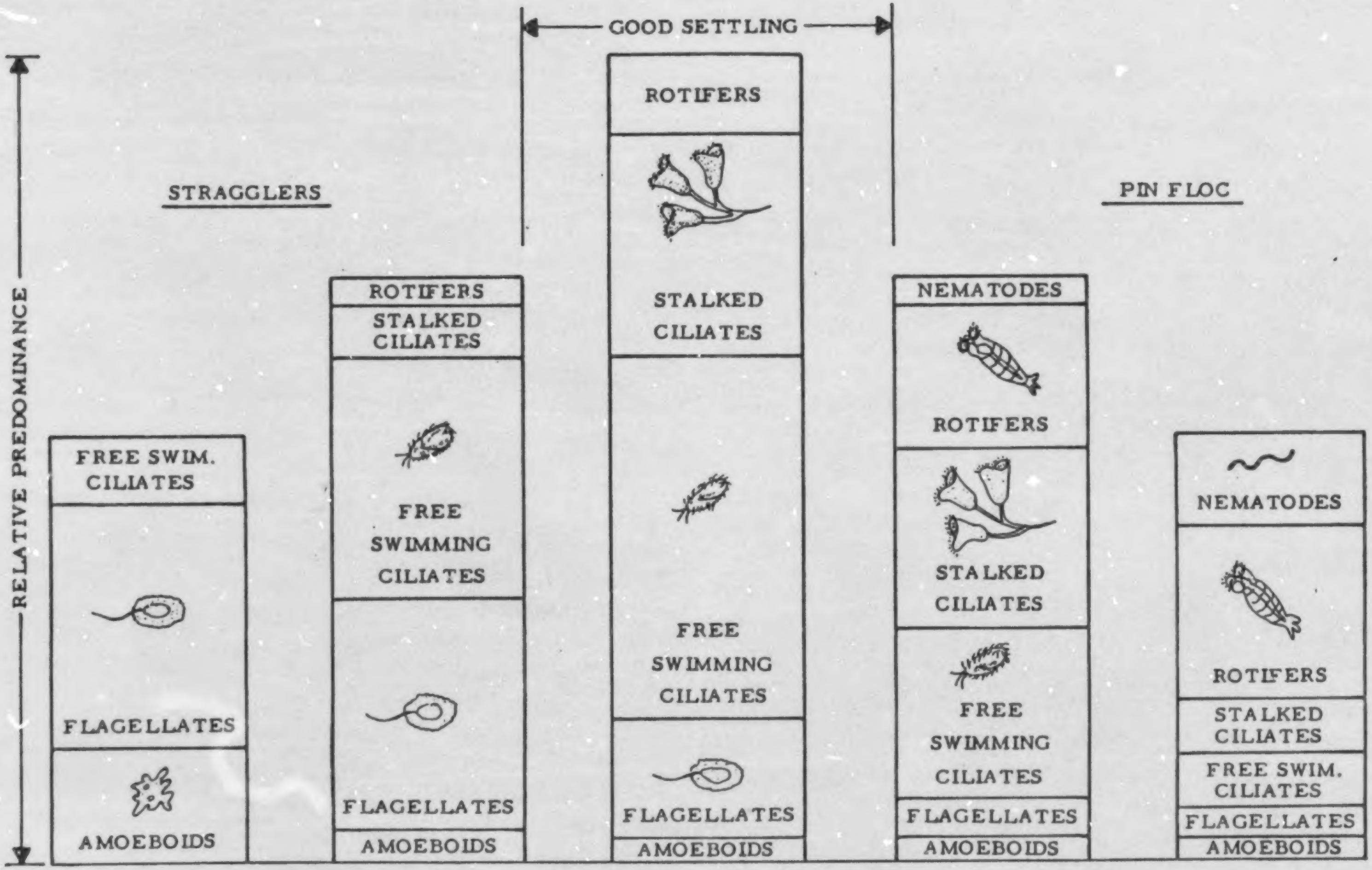
Observation of microorganism activity and predominance in the activated sludge can provide guidance in making process control adjustments. Study of Figure 3 can be used to assist the operator with the decision of increasing or decreasing the MLSS based on the relative predominance of ciliates and rotifers in the MLSS. The decline of ciliates and rotifers is frequently indicative of a poorly settling sludge. These observations make it possible to detect a change in organic or chemical loading before an upset occurs. These changes can be compared with other observations such as the settling characteristics of the MLSS in the 30-minute settling test, and F/M calcuations. If the other tests confirm these observations, adjustments to the MLSS should be made to alleviate the problem.

In summary, relative predominance of ciliates and rotifers are an indication of process stability. This predominance is associated with the efficiency of treatment under various loading conditions. An increase or decrease in the predominance of these organisms may be indicative of process upset before there is a major effect on process performance.

A great deal of information can be provided if photographic records of sludge conditions are kept in a systematic and well documented manner. Inexpensive (approximately $100) Polaroid cameras are available for this purpose, and it is strongly recommended that a camera of this type be obtained along with the microscope. These photographic records can be used to anticipate seasonal variation or conditions of unusual operation. Table 1 is also useful for tracking relative numbers of higher life forms.

Bacterial Age:

When food is abundant bacteria grow and reproduce quite fast and assimilative respiration and solids production are highest. When food starts becoming limited, growth slows down and more of the food is required for cell maintenance.



RELATIVE NUMBER OF MICROORGANISMS VS. SLUDGE QUALITY

FIGURE 3.

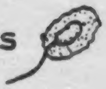
TABLE 1.

WORKSHEET FOR MICROSCOPIC EXAMINATION OF ACTIVATED SLUDGE

DATE: ______________________ TIME: ________ AM PM

BY: ______________________ TEMP: ________ °C

SAMPLE LOCATION: ______________________________________

MICROORGANISM GROUP	SLIDE NO. 1	SLIDE NO. 2	SLIDE NO. 3	TOTAL
AMOEBOIDS				
FLAGELLATES 				
FREE SWIMMING CILIATES				
STALKED CILIATES				
ROTIFERS				
WORMS				

RELATIVE PREDOMINANCE:

1. ______________________________

2. ______________________________

3. ______________________________

When food is abundant, the bacterial generation time is quite fast, and we call the bacteria "young" because each cell is around for a very short time before it divides. A "young" group of cells or "young" sludge can generally be characterized in the following:

1. Short generation time.
2. Higher VSS (Volatile Suspended Solids) production.
3. Higher degree of motility.
4. Lower degree of floc formation.
5. White, billowy foam.
6. Slow settling, poor compaction.
7. High F/M ratio.

Keep in mind that young sludge is based on average organism age. Some are younger than the average, some older, but on the average, the cells are growing and dividing quite fast.

In contrast, as foods become less abundant, either due to less food in the system or more organisms in the system to compete for the same amount of food, the bacterial generation time is slower. This means that each individual cell is around longer before it divides. Thus the cells are termed "older". An "older" sludge is characterized by the following:

1. Longer generation time.
2. Lower VSS production.
3. Lower degree of motility.
4. Higher degree of floc formation, although an extremely old sludge will start to lose its floc formation ability because there are not enough live bacteria to stick together.
5. Darker, leathery foam.
6. Faster settling.
7. Low F/M ratio.

Again, keep in mind that this is an average condition; some bugs will be very old, some much younger, but the average cell is considered old.

Sludge age is controlled by the amount of sludge in the system, since food coming into a system normally stays relatively constant. In this case, the only way to vary the generation time of the bacteria is to vary the number of bacteria in the system. If little or no sludge is wasted, the number of bacteria will increase, thereby limiting the amount of food available for each bacteria and making the sludge "older". If more sludge is wasted, fewer bacteria remain, more food is available for each bacteria, and the sludge becomes younger.

In certain cases a condition can develop in which a young and an old sludge exist together. This is most often seen in extended aeration systems. Extended aeration normally operates with little food available for each organism; it contains an older sludge. But what happens if the sludge accumulates to the point where sludge must be wasted and the operator wastes a very large amount of sludge, say 50% (a very common practice). Since the amount of food entering the system normally stays about the same, the food to microorganism ratio immediately doubles with 50% sludge wasting. Since some cells are relatively young compared to the rest, they are at a higher rate of activity (more active enzyme production and growth) and more ready to grow. If the F/M ratio increases, it means more food is available per bug, and those younger bugs ready to grow will grow because more food is available. In contrast, an old bug has to develop and generate enzymes for growth. So, the younger bugs grow while the older bugs are getting ready to grow. Thus, two distinctive types of bugs begin to develop in the same sludge. The younger bugs will control the settling; if there are too many young bugs, sludge settling will deteriorate, many times to almost a "bulking" condition.

You can generally tell when a "two-sludge" system develops by observing the foam, settling test, compaction characteristics and floc carry-over. Fine, light particles of straggler floc are usually seen, settling is relatively slow for having that amount of sludge in the system and there is generally poor compaction. The most easily seen indication is two types of foam on the aeration tank with the aerator off. The foam will form into bands with one band being relatively light and fluffy, the next being thick and leathery. Generally, a slow, but constant, wasting program is required to eliminate the condition.

This points up the fact that activated sludge, even the extended aeration mode, does not like large or fast changes in environment. When wasting sludge, it is best to waste a little sludge quite often rather than a lot of sludge every once in a while. The bugs don't like the latter case and will show their dislike by developing poor sludge conditions. Thus any activated sludge system should have sludge holding or digestion facilities available to follow frequent wasting of small amounts of sludge.

Contact Stabilization:

In conventional activated sludge and extended aeration systems, all of the adsorption, absorption, and energy production processes are going on at the same time in the same tank. On the other hand, the contact stabilization process separates these activities somewhat. As you remember, this process contains a contact tank, clarifier and reaeration tank. In the contact tank, raw sewage is contacted with return sludge for a very short time (15-30 minutes) where adsorption takes place along with some absorption of dissolved materials. There is not enough time for adsorbed food to begin metabolizing and thus little breakdown of nutrients occurs.

The mixed liquor passes to the clarifier where the bacteria and adsorbed materials settle. Since there is little D.O. in the clarifier, the bacteria are slow to begin exocellular digestion, absorption, energy production, and protoplasm production.

The return sludge is sent to a reaeration tank where oxygen and mixing are provided for about 4-6 hours. Exocellular digestion and absorption are completed and the bacteria breaks down the ingested food. Some reaerated sludge is wasted, the rest is returned to the contact tank to absorb nutrients and the process starts over again.

This mode of operation is well suited for raw sewage where the oxygen demanding materials are mostly particulate or where a conventional system is overloaded. It is not good where much of those materials are soluble.

An important concept to remember involves the contact time. Nothing is to occur in the contact tank other than adsorption, a small amount of absorption and maintenance of life within the cell. If cells begin growing, poor sludge settleability occurs in the clarifier and removal efficiency is poor. Therefore, you must not have a long contact time. Most package plants have too long a contact period, thus growth occurs in the clarifier and the plant does not work.

Floc Formation:

As most bacilli and cocci begin growing, they generally develop into small chains or clumps. Very tiny particles such as these do not settle well because the bugs are motile, very active, and do not have a well developed slime layer. Therefore, when mixing occurs, the clumps and chains break up, the bugs are dispersed, and they won't flocculate or settle.

If the sludge is allowed to age, the bugs lose their flagella and motility and accumulate more slime. Thus, the chains and clumps are better able to stick together. The clumps grow bigger and bigger until they form a floc. Any very small clumps or chains which contact the floc tend to stick to the floc also. If the critters are allowed to develop properly, under the right conditions, the floc gets large and compacts enough to be slightly heavier than water, thus it settles.

Mixing in an aeration tank tends to keep the floc small since, even though the bugs are sticky, the bond formed holding the critters together is not very strong. This is good because it allows the cells, food, and oxygen to contact each other and waste metabolic products to be taken away from the cell. But if too much mixing is provided, good, compact, heavy floc does not develop and settleability is retarded.

Good, strong floc is developed when a filamentous organism can grow in the interior of the floc. These organisms are well suited for growth under adverse conditions of low concentrations of oxygen and nutrients even though they are obligate aerobes. The interior of a floc provides these conditions because the organisms around the filamentous organisms utilize most of the nutrients and oxygen, leaving little for the filament. Other organisms could die under such conditions, allowing the floc to break up. The filament will survive, serving as a backbone holding the floc together.

Filamentous organisms such as species of Sphaerotilis and Thiothrix are normally considered nuisance organisms, but from the above discussion, you can see that they can be beneficial and not always a nuisance. They definitely become a nuisance though when the entire growth environment presents adverse conditions such as high organic loading, low D.O., etc. When poor conditions exist outside the floc, the filaments can compete better than the normally predominant activated sludge microorganisms and the filaments extend outside the floc. If such conditions continue to persist, the filaments will grow to the point where they contact filaments from other floc particles. This develops a bulky sludge of very poor settling quality.

Activated sludge floc comes in many shapes and sizes. We've discussed the higher life forms in activated sludge but little attention has been given to the floc itself. There are three basic types of floc:

Pin Floc - Basically, we know that pin floc is small, dense and 50-70 microns in diameter. These represent an under-oxidized sludge or one with little growth pressure. We called this an old sludge. This floc is associated with SVI's of about 50.

Bulking Floc - We also know that a large feathery floc which has many external filaments represents young sludge with SVI's greater than 200. This floc is usually found under high organic loadings or in some type of growth stressed environment.

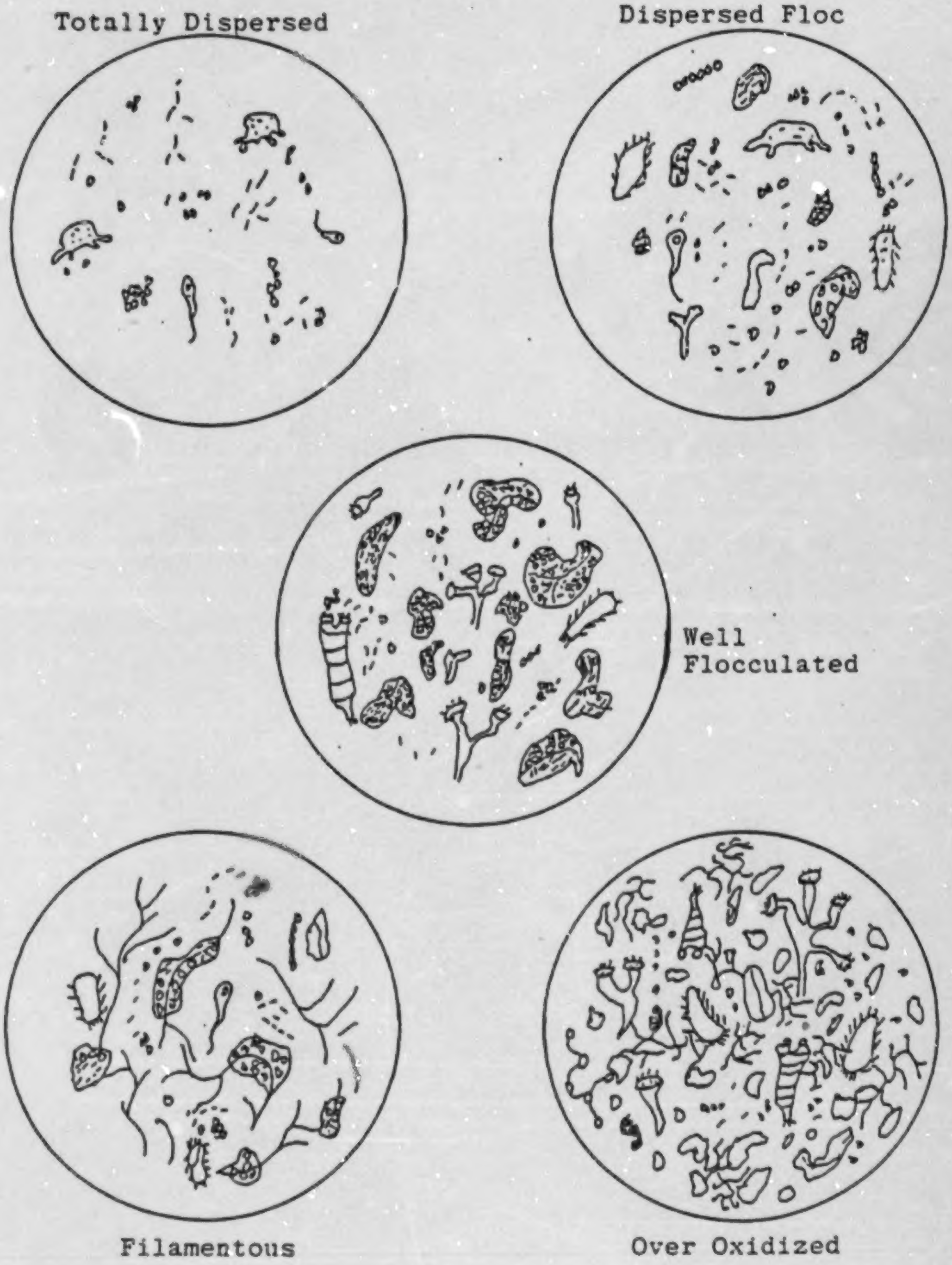
Normal Floc - A third floc, which we'll call Normal, is non-bulking but still has some filaments. SVI's of 100-150 and a size of 100-500 microns in diameter. This floc is found when there is a good balance between environmental and physical conditions.

The key is in the length of protruding filaments and in the ability of bacteria to stick together. The obvious effect of floc size is in the settleability of the sludge. Settleability is a direct function of size and density.

The length of protruding filaments is also a significant factor in sludge settleability. Filament lengths of 10^7 μ/ml which is approximately 30 ft./ml of filaments provide a typical SVI of 100-150. In reality, the floc found in any plant will be a combination of the two extreme conditions. It is the operator's job to interpret these conditions. The following Table 2 and Figure 4 provide some presentations of typical conditions.

TABLE 2. General Sludge Characteristics and Associated Microorganisms

	Sludge Condition	Characteristics	Bacterial Predominance	Protozoan Population
1.	Totally Dispersed Sludge	No settling, turbid supernatant, poor BOD removal, very, very low MLSS	Very young bacteria, motile, very active growth, no flocculation	Mostly flagellates and sarcodina, few ciliates.
2.	Dispersed Sludge	Little settling of sludge mass, turbid supernatant, some flocs	Young, actively growing bacteria, mostly dispersed, but some flocculation	Flagellates present, some free swimming and stalked ciliates
3.	Poor, Flocculated Sludge	Very slow settling, very clear supernatant except for straggler floc, light color	Young bacteria, very light, fluffy flocs often held together by bridging of filamentous bacteria	Few flagellates, many free swimming ciliates, some stalked ciliates
4.	Well Flocculated	Good settling, clear supernatant; well developed, compact flocs	Mature bacteria, well flocculated, some filaments	Very few flagellates, some free swimming ciliates, many stalked ciliates, some rotifers
5.	Old, over oxidized sludge	Hindered settling; clear to slightly turbid effluent; small, granular flocs, dark color, high MLSS, low MLVSS	Fewer live bacteria, much cell debris, very slow growth, reduced flocculation	No flagellates, numbers of ciliates and rotifers about the same



Totally Dispersed

Dispersed Floc

Well Flocculated

Filamentous

Over Oxidized

FIGURE 4. Various Sludge Conditions as They Might be Seen Through a Microscope.

Lesson 4: Sludge Quality

In the last lesson we introduced the term Sludge Quality. Sludge quality was defined as the right mixture of organisms that produced a good effluent. We also talked in general terms about how the organisms competed with one another, how the organisms formed floc, and how the various types of floc could impact the quality of effluent. The age of the organisms was also pointed out to affect sludge quality. Young, highly mobile bacteria do not flocculate very well. The food level relative to the organism population was also shown to impact the energy state of the organisms and their relative growth rate, which, in turn, would affect their ability to efficiently remove BOD.

The state-of-the-art for measuring sludge quality, however, is still primitive. One key problem is in measuring the quantity of "active biomass". Active biomass is the collective sum of all the living organisms that contribute to treating sewage. The first problem is that we can't differentiate very well the difference between living organisms and dead organisms. Secondly, each type of organism needs to have its own weighting factor to determine its relative role in treating sewage. Since there are hundreds and hundreds of different organisms in the biomass, it would be almost impossible to quantify that relationship.

Another problem is one which we refer to as "steady state". Steady state, for a biological treatment system, means that all factors affecting their performance remain constant. The temperature is constant, the D.O. is constant, the food level is constant, the food type is constant, and on and on and on. None of these are actually constant for a wastewater treatment plant. Therefore, we have a problem measuring sludge quality. But it isn't hopeless!

Oxidation Pressure:

Much work has been put into improving the tools for measuring sludge quality. Before we address these tools, however, there is one other concept that needs further definition. That concept is oxidation pressure. We defined that concept in the last lesson as the impact of food (substrate) on the growth patterns of microorganisms. In a more general sense, there are a number of parameters that affect growth and consequently sludge quality. There are also a number of parameters that can be measured which indicate a response to a growth pressure. This understanding becomes the foundation for a very powerful tool for controlling activated sludge systems and that is monitoring the impact of sludge quality through tracking the responses and the forces exerted on the system. We call these oxidation pressures. Figure 1 depicts an oxidation pressure scale. The figure shows that high oxidation pressure produces under oxidized sludge and that low oxidation pressure produces over oxidized sludge. We learn to talk in terms of "over oxidized" and "under oxidized" sludge. The ideal state is to control the activated sludge system with a balanced oxidation pressure. When this system is in balance at a desirable point then it can be said that the sludge quality is good and that good effluent quality can be expected.

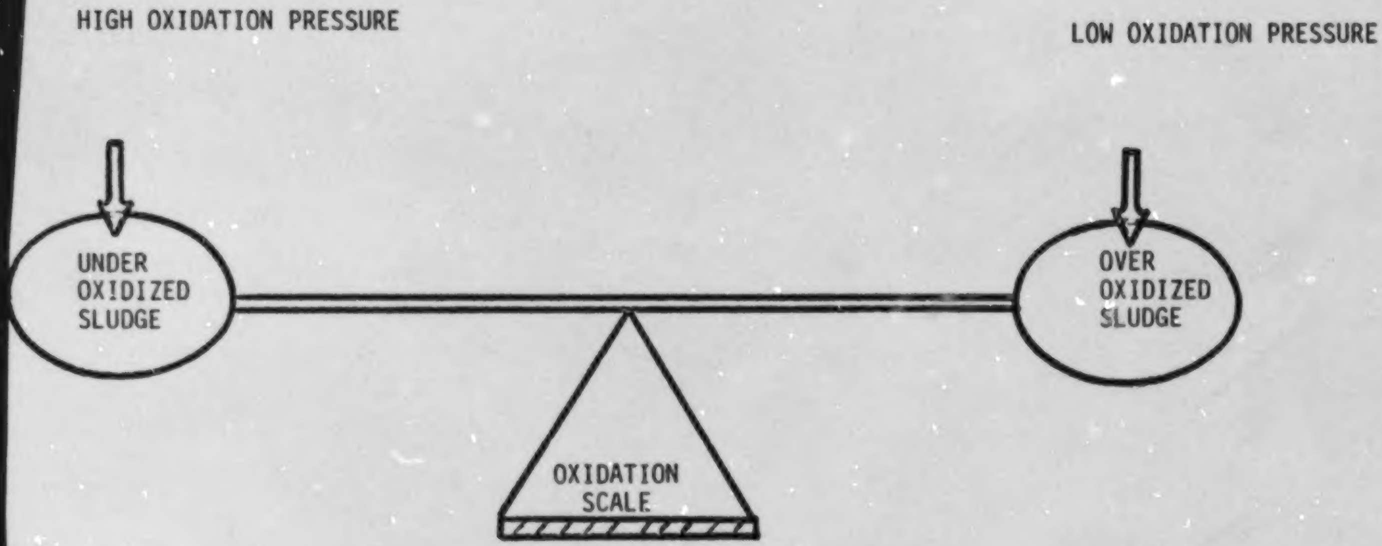
The following sections will address some specific tools for monitoring sludge quality through biological, biochemical and physical characteristics. Later sections will demonstrate examples of how these tools can be used to make collective judgments on sludge quality.

Observations and Responses:

Aeration tanks and final clarifiers are studied carefully for informative physical characteristics that help identify sludge quality and process status. They are scrutinized for clues that indicate the kind of control adjustments needed to achieve optimum plant performance. The inferences of such physical findings are used to supplement the results of other more specific control tests that dictate the direction and magnitude of the essential control adjustments.

Much can be learned from simple but perceptive sensory observation of process features such as the type, color, and extent of foam on the aeration tank surface and the presence or lack of scums and rising floc particles in the final clarifiers. From such observations, a skilled operator usually can determine the basic phase his process is moving towards or is locked into.

FIGURE 1. OXIDATION PRESSURE SCALE


HIGH OXIDATION PRESSURE
LOW OXIDATION PRESSURE
UNDER OXIDIZED SLUDGE
OVER OXIDIZED SLUDGE
OXIDATION SCALE

Such observations will make him aware of more generalized long-term requirements. They will help him reach proper conclusions from the results of other, more specific, control tests that are used to calculate process demands and to determine the type and extent of control adjustments that are actually needed.

The entire series of physical observations described in this lesson should be made and recorded (Figure 2) each time the routine control tests are performed. The appearance of the final effluent and the aeration and clarifier tank contents should be examined at least once during each operator's eight hour shift.

Aeration Tanks:

Turbulence

The operator should observe the entire aeration tank surface for turbulence. Though some of his conclusions will be subjective and based on past experience, the extent of surface turbulence will indicate whether or not all sewage, return sludge, and mixed liquor are thoroughly mixed throughout the entire aeration tank. Observable surface characteristics will imply whether or not dead spots or insufficiently mixed core areas may exist within the aeration tanks. The operator should maintain, increase, or decrease air discharge rates according to the conclusions he reaches from the results of such observations and from supplementary dissolved oxygen determinations.

He obviously should reproportion air flow through headers or individual sub-headers to correct any dead spots, unequal air distribution, or inadequately tapered aeration intensity that may have been observed.

If serious mixing deficiencies prevail despite corrective air distribution adjustments, he should attempt to determine which structural, mechanical or design deficiencies may be responsible for the difficulties. If normal air balancing procedures fail to correct evidence defects, he should be prepared to recommend the maintenance or modification procedure that may be necessary to eliminate the problems or to look further into a potentially unique problem in the load.

In many cases, aeration deficiencies can be corrected by routine diffuser cleaning or by replacing existing diffusers with more effective maintenance free units. In some cases major mechanical alterations may be required to relocate and increase the number of diffusers to mix and aerate the tank contents thoroughly. Overall process performance has been improved at some plants by replacing the single run of diffusers that extended along one side wall with multiple parallel runs of diffusers extending either longitudinally or across the tank bottom.

Surface Foam and Scum

The type of foam or scum, if any, accumulated over the aeration tank surface, and to a lesser extent, the color of the mixed liquor sludge reveal process status and indicate generalized long-term sludge wasting requirements.

Fresh Crisp White Foam

Only a modest accumulation of white, or at least light colored, crisp appearing foam is usually evident on aeration tank surfaces when an excellent final effluent is produced by a properly balanced activated sludge process. Under such circumstances the operator should continue his successful control policies until the physical characteristics or the results of other control tests diverge from optimum.

Excessive Billowing White Foam

If the aeration tanks are covered by thick voluminous billows of white sudsy foam, the operator can be quite certain that the sludge is too young and that sludge age should be increased by reducing the sludge wasting rate.

Sludge age, which is controlled by the sludge wasting rate, indicates the approximate number of days that the activated sludge remains in the system before being discarded. Prolonged excessive sludge wasting will reduce sludge age by increasing the proportionate amount of newly developed floc in the system. Conversely, unduly low wasting rates will increase the number of days the sludge is retained in the system and will increase the proportionate amount of older sludge.

Sludge wasting rates should be decreased only gradually on a day-to-day basis to correct the process imbalance that was revealed by the excessive white foam. Best results are usually obtained by reducing the wasting rate approximately twenty percent on each successive day until all observations and tests reveal improving trend lines. When positive improvement is noted, the operator should maintain the lowered wasting rate for about three more days while the improving trends are confirmed. He should, of course, continue to plot and review process control and response trend lines which will alert him to subsequent control adjustment policy that may become necessary. As implied previously, wasting usually should not be discontinued completely.

Operators who have actually gone through this white foam cycle realize that not all foam is caused by detergent.

Thick, Scummy, Dark Tan Foam

At the other extreme, the operator may observe a more dense and somewhat greasy scummy layer of deep tan to brown foam covering the entire aeration tank surface. Such a foam almost always indicates that the sludge is too old and possibly over oxidized. The obvious answer is to increase sludge wasting rates. Here again, the sludge wasting rate should usually be increased modestly, possibly ten to twenty percent per day, on a day-to-day basis while observing trend lines to determine the maximum wasting rate that should be maintained until the difficulties are overcome and the process is restored to proper balance.

The dark tan, viscous foam on aeration tanks may contain large amounts of *Nocardia*. Microscopic examinations of mixed liquor and foam samples can be used to monitor the *Nocardia* population. Generally, an increase in *Nocardia* results in an increase in this type of foam. Increased sludge wasting will usually eliminate the *Nocardia* and foam. Chlorination of the waste and return activated sludges and the foam will also aid in the elimination of this foam. In the meantime, process control conditions should be altered to discourage *Nocardia* growth by increasing growth pressures. Foam suppresent chemicals can provide immediate relief while more fundamental corrective actions are taken.

Sludge Color and Odor

At times a poor quality, extremely dark-brown-colored sludge, sometimes almost black, releasing hydrogen sulfide odors, may be observed in the aeration tanks. It does not take much experience to recognize this problem. Most operators would logically increase air discharge rates immediately to provide 2-3 mg/l D.O. throughout the tank contents. In severe cases, when such color and odor persists, despite proper control measures, they should question the adequacy of the aeration devices installed at their plants. Under such circumstances, the operator should clean or replace the existing diffusers and recommend appropriate mechanical modifications as discussed in the section on turbulence and mixing.

Secondary Clarifiers:

The operator should also observe the final effluent and the clarifier water surface critically for additional clues which indicate process phase and balance, and supplement the results of other control tests to determine sludge wasting and air control requirements.

Secondary Effluent Appearance

If the final effluent appears clear and attractive, or is improving day by day, and all control measurements are in the proper range, then obviously the operator should continue his present control policy.

Conversely, if it appears turbid or contains noticeable solids, he should modify his operational control policies and procedures. Though observation of poor effluent quality alone will not reveal specific control requirements, it signals the need for judicious review of control and response trend lines and for revised operating policies. Specific control adjustments will be dictated by the results of other control tests. Turbidity measurements of the effluent provide a quantitative measurement of effluent quality.

Sludge Bulking

Operators who have experienced true classic sludge bulking find it all too easy to remember and identify. Such conditions are evidence by a homogeneous appearing sludge blanket that extends throughout the entire clarifier, and can be observed at the water surface while the mixed liquor solids pour out over the final effluent weirs. Though at times induced by shock loadings, and aided and abetted by ineffective aeration devices, classic sludge bulking usually is caused by improper operational control rather than by inadequate plant capacity. Furthermore, impending bulking usually can be recognized many days before it actually occurs by judicious use of the sludge depth blanket finder, settleometer, and microscopic analyses.

This type of bulking, which is practically always associated with under-oxidized sludge (low D.O., high F/M or low nutrients), usually can be eliminated by reducing sludge wasting rates and balancing other growth pressures. Where appropriate flexibility has been designed into plants, bulking has also been eliminated by changing the process variation from conventional plug flow to step feed; introducing the primary effluent into the second or third bay of the aeration tank.

In emergency situations, chlorination of the return activated sludge may be used to provide temporary relief. This practice has been used extensively as a means for controlling bulking, but it should be used continuously and only on a temporary basis when filamentous growths are involved.

In some cases where such control adjustments have failed, emergency chemical treatment has helped the system recover from classic sludge bulking. Some operators have successfully applied polymers and ferric chloride or alum to the mixed liquor entering the final clarifier without destroying desirable sludge characteristics. Laboratory jar tests should be performed to indicate the type of chemical, the dosage rate, and the pH range that will be most effective. If the chemical additives do not improve the settleability in the final clarifiers, even though the sludge samples settled and compacted in the laboratory jar tests, the chemicals should be added at different points between the aeration tanks and the final clarifiers until best results are obtained. It is usually best to apply chemicals to the wet well preceding, or the pipe line leading to, the final clarifier.

Sludge Solids Washout

Excessive sludge washout over the final effluent weirs, when the upper surface of the sludge blanket is more than three feet below the clarifier water surface and when sludge settles properly in the laboratory, should not be confused with classic sludge bulking. At times this type of severe effluent degradation has been observed while the settleometer test revealed excellent sludge quality. In many multiple clarifier plants this has been caused by unequal mixed liquor flow into, or by unequal return sludge removal from, individual final clarifiers. Under such circumstances, every effort should be made to balance flows into and out of the clarifiers.

Solids washout, which differs from classic sludge bulking, is more frequently caused by hydraulic overloading, toxic substances (such as high pH, heavy metals, phenols, etc.) or inappropriate secondary clarifier design. Consequently, changes in process control parameters are of little benefit.

Clumping and Ashing

At times, large masses of sludge, possibly one foot in diameter, may be seen rising, then bursting, and finally spreading over the clarifier surface. This has sometimes been called "clumping". At other times, smaller sludge particles usually deep brown to gray in color, may rise and then spread over the tank surface. Some operators call this "ashing". This problem occurs when sludge age has been permitted to increase beyond the optimum equilibrium requirement of the process cycle. Nitrified sludge undergoing denitrification in the clarifier releases nitrogen gas which is trapped in the sludge causing it to flash. It can usually be eliminated by increasing sludge wasting rates or return rate. Reducing air discharge rates to the minimum levels that will still maintain aerobic conditions in the aeration tanks has also been helpful.

Straggler Floc

At times, small, almost transparent, very light fluffy, buoyant sludge particles (one eighth to one-quarter inch in diameter) may be observed rising to the clarifier surface near the outlet weirs. This condition is usually intensified in a shallow clarifier and may be especially noticeable at high return sludge flow rates. When this type of straggler floc is observed while the final effluent is otherwise exceptionally clear, and particularly if it prevailed even during relatively low surface overflow rates, it implies that sludge age should be increased moderately towards optimum. Since this type of straggler floc usually occurs at relatively low mixed liquor solids concentrations and is usually intensified during the early morning hours, it is believed that these particles are fresh, low density portions of new sludge that has been built up over night. Straggler floc formation can be minimized, and usually eliminated, by reducing sludge wasting rates moderately to increase sludge age while return sludge and air discharge rates are controlled to meet process demands calculated from other control tests. Moderate sludge blankets maintained by low return rates may also be effective for minimizing straggler floc.

Pin Floc

At other times, very small, compact pin floc, usually less than one thirty-second of an inch in diameter, may be observed suspended throughout moderately turbid final clarifier tank contents. This is a strong indication that sludge age has been increased unduly, and the sludge has become over-oxidized. This will be confirmed by the settleometer test if rapidly settling discrete sludge particles appear granular rather than flocculant, and accumulate rather than compact while forming a settleometer sludge blanket. In essence, granular sludge particles were falling through a turbid liquor rather than compacting and squeezing out a clear final effluent.

When these final clarifier characteristics are confirmed by the settleometer test, the sludge wasting rate should be increased while return sludge flow is adjusted to meet other control test demands.

Kinetic Parameters:

Kinetic parameters may first sound like a subject for engineers; but the principles are important in operations as well as design. As defined in a common dictionary, kinetic is an adjective which means "of or resulting from motion". Design engineers are interested in the rate at which a reaction proceeds. In operations, our interest is in tools that help us decide if the rate (kinetic) is increasing or slowing down; i.e., the rate of the oxidation or cellular respiration. In this section we will define tools that help evaluate oxidation pressure. These tools have a kinetic derivation because they all relate to the reactions (kinetics) of the biomass. These tools include F/M, MCRT, Respiration Rate (RR) and Yield.

F/M and MCRT

F/M and MCRT are classic parameters that are used by many operators to operate their wastewater treatment plant. Experience has shown that typical values for these parameters are:

F/M: 0.2 - 0.5

MCRT: 5 - 15 days

The following discussion provides more detailed discussion.

Food/Microorganisms Ratio

The food to organism loading ratio is based upon the food provided each day to the microorganism mass in the aerator. Food provided is preferably measured by the COD of the influent to the aerator. COD is recommended because test results are available within four hours and process changes can be made before the process becomes upset. Many operators load aerators on the basis of the BOD test, but results five days later are too late for operational control. Typical loading parameters have been established for the three operational zones of activated sludge and are summarized as follows:

1. High-Rate

   COD: 1 lb COD per day/lb of MLVSS under aeration.
   BOD: 0.5 lb BOD per day/lb of MLVSS under aeration.

2. Conventional

   COD: 0.5 to 1.0 lb COD per day/lb of MLVSS under aeration.
   BOD: 0.25 to 0.5 lb BOD per day/lb of MLVSS under aeration.

3. Extended Aeration

   COD: 0.2 lb COD per day/lb MLVSS under aeration.
   BOD: 0.05 to 0.10 lbs BOD per day/lb MLVSS under aeration.

Mean Cell Residence Time (MCRT)

Another approach for solids control used by operators is the Mean Cell Residence Time (MCRT) or Solids Retention Time (SRT). The terms are almost the same. The equation for MCRT is:

$$\text{MCRT} = \frac{\text{lbs S.S. in Total System}}{\text{lbs S.S. Wasted/day} + \text{lbs S.S. Lost in Eff./day}}$$

The most desirable MCRT for a given plant is determined experimentally. The desired MCRT for conventional plant operation should fall between five and fifteen days. Don't confuse this time with the recommended range for Sludge Age of 3.5 to 10 days which has a different calculation procedure.

Required Data:	Units
1. Aerator	MGD
2. Final clarifier biomass	Lbs
3. Wastewater flow to aerator	MGD
4. Waste sludge flow for past 24 hours	MGD
5. Mixed liquor suspended solids concentration	mg/l
6. Waste sludge (or return sludge) suspended solids concentration	mg/l
7. Final effluent suspended solids concentration	mg/l

Because MCRT calculates the solids residence time, we often refer to the MCRT value as the age of the biomass. A MCRT of five days literally means that the biomass has stayed in the system for an average of five days. Experience has shown that this is proportional to the bacterial age as defined earlier. Therefore we can define the terms of young sludge as MCRT less than 5 days, and old sludge as MCRT greater than 15 days. Sludge age, cell residence time, and solids residence time represent other calculation techniques for determining the same principle.

Many plants consider only F/M and MCRT when there actually is a relationship between them. Without going into the mathematical derivation, this relationship can be defined as:

$$1/MCRT = Y'(F/M) - K_D$$

Where: 1/MCRT is the growth rate

Y' is the sludge yield

F/M is the loading factor

K_D is a destruction rate

As previously stated, other manuals or reports may use sludge age, cell residence time or solids residence time instead of MCRT. These terms all attempt to calculate the average time the biomass stays in the plant. For the purpose of operations it is not important which term is used, but it is important that the definition and calculation be clearly understood.

The assumptions and general steps used for the derivation of MCRT and F/M are defined in Figure 3. Now, you may ask why is this important for an operator. The answer is, it is important to understand the assumptions, and therefore, the limitation of any control parameter used. Without this understanding an operator may find that he is making decisions or a control parameter that are not relevant for his situation. Such as example would be the case where an operator is running his plant on a fixed MCRT concept. However, in the middle of the month an industry changes its production rate and doubles the load to the plant. At this point in time new control decisions have to be made, but by looking at only MCRT data, the plant would fail before the operator could make an operational change.

When using F/M and MCRT there are some specific assumptions that must be verified. Any operator responsible for making process decisions must verify the following:

1. An accurate measurement of the system solids (including aeration tanks and clarifiers) is used;
2. The solids measured are a representative measurement of the "active biomass," such as using MLVSS to measure bugs;
3. Measurements of WAS and secondary effluent suspended solids must represent the loss of "active biomass" from the system;
4. Measurements of influent and effluent food (BOD, TOC or COD) must represent the food available and the food utilized by the "active biomass";

FIGURE 2. ACTIVATED SLUDGE OBSERVATIONS

AERATION TANK	MON	TUES	WED	THUR	FRI	SAT	SUN
Color of Sludge							
Color of Foam							
Characteristics of Foam							
Odor							
Comments:							
FINAL CLARIFIERS							
Color							
Clarity							
Appearance							
Bulking							
Solids Washout							
Clumping							
Ashing							
Straggler Floc							
Pin Floc							

FIGURE 3.

DERIVATION OF F/M & MCRT

		ASSUMPTIONS
1.	KINETICS	EXPLAINS BIOCHEMICAL REACTIONS FOR GROWTH
2.	EQ'S. FOR GROWTH RATE	GENERALLY ASSUMES GROWTH IS LINEAR TO AVAILABLE FOOD
3.	EQ'S. FOR MASS BALANCE OF SYS.	1. STEADY STATE 2. "ACTIVE BIOMASS" (SYSTEM) 3. IN-OUT MEASUREMENTS 4. WASTE = GROWTH + EFF. TSS
4.	SLUDGE YIELD	ACTIVE SYSTEM BIOMASS

5. ⇨

$$\boxed{1/MCRT = Y' \times F/M - K_D}$$

Where
$1/MCRT$ = growth rate
Y' = sludge yield
F/M = loading factor
K_D = destruction rate

5. There must be no limitations to growth other than available food, i.e., detention time, D.O., nutrients, temperature and mixing and toxic materials must not be limiting;

6. The system must be operating in a "steady state" condition (1-2 weeks), i.e., the ratio of food provided to the amount of "active biomass" must remain constant.

Yield

Yield or sludge yield is a concept that was defined briefly in an earlier lesson. This concept is important in that it provides a common and practical comparison from one period of events to another period of events. The calculation of yield (Y) is very simple. For the purposes of this work, we refer to an observed yield which is defined as the ratio of:

$$Y = \frac{\text{lbs of biomass produced}}{\text{lbs of BOD}_5\text{ fed}}$$

This can also be interpreted as:

$$Y = \frac{\text{lbs of net biomass wasted}}{\text{lb of BOD}_5\text{ fed}}$$

Where the word "net" includes gains such as influent solids and losses such as endogenous respiration activity and protozoa predication. From an operational standpoint we are interested in the change in the observed yield from season to season as this will change the solids handling considerations and consequently the operational budget. Tracking the yield also provides information that can be used to optimize treatment costs. The yield can be changed by changing process variables such as primary treatment efficiency, D.O.'s, MCRT's and the number of aeration tanks in service.

Respiration Rate (RR)

Microorganisms use the dissolved oxygen in the water to supply energy for new cell growth. The amount of oxygen available at any given time is directly measured as dissolved oxygen (D.O.) in units of mg/l. If we determine how active the microorganisms are we can gain another parameter for monitoring oxidation pressures. To do this it is necessary to measure the rate of which a certain amount of microorganisms use a given amount of oxygen. An under oxidized sludge with sufficient absorbable food available will use oxygen at a high rate. One must remember that temperature also influences biological activity; therefore, the rate of oxygen usage will be greater during the warmer seasons.

Definition: RR = mg/l O_2 used per hour per gram of MLSS

Oxygen uptake, or oxygen uptake rate, which is the term used for rate of oxygen usage, is defined as the weight of oxygen consumed per unit time expressed in units of mg/l per hour. In order to standardize the oxygen uptakes, respiration rate (RR), which relates oxygen uptake rate to a specific weight of sludge at a definite time, is calculated. The respiration rate can indicate problems before clarifier upsets occur by providing almost immediate answers on current biological activity in the mixed liquor just as it leaves the aeration tank. Remember that as with other control parameters respiration rate trends over a given period of time should be considered in conjunction with all other process indicators when evaluating operational changes.

To calculate the respiration rate, it is necessary to measure the oxygen uptake rate and obtain the concentration of mixed liquor suspended solids in mg/l. The oxygen uptake rate is measured according to the following steps:

1. Measure D.O. and temperature in the basin at the sampling point.
2. Collect a sample of mixed liquor from the aeration tank and saturate it with air by gently shaking it 25 times in a partially filled container. The initial D.O. in the bottle should be about 6 mg/l.
3. Insert a D.O. probe and record the D.O. initially and at one minute intervals until an approximately constant change in D.O. has been obtained for at least three successive readings or until the D.O. has dropped to less than 0.5 mg/l.
4. Determine the average change in D.O. per minute by averaging the approximately constant D.O. changes (D.O. per minute).
5. To get the oxygen uptake rate in mg/l of oxygen per hour, multiply the average change in D.O. per minute by 60 min./hr.

Example:

The following is typical data that should be collected when calculating the respiration rate:

Item	Value
Temperature of mixed liquor	22°C
D.O. of mixed liquor	2.8 mg/l
Mixed liquor suspended solids concentration	2400 mg/l

Time, min.	D.O., mg/l	Δ D.O., mg/l
0	6.4	--
1	5.8	0.6
2	5.4	0.4
3	4.9	0.5
4	4.5	0.4
5	4.1	0.4
6	3.7	0.4
7	3.4	0.3
8	3.0	0.4
9	2.6	0.4

Calculation of respiration rate:

1. Average D.O., mg/l/min.

$$\frac{D.O._2 - D.O._9}{t_9 - t_2}$$

$$= \frac{5.4 - 2.6}{9 - 2} = 0.40 \text{ mg/l/min.}$$

2. Oxygen uptake rate, mg/l of oxygen per hour

   Average D.O., mg/l/min X 60 min/hr

   = 0.40 mg/l/min X 60 min/hr = 24 mg/l/hr

3. Respiration rate, mg of oxygen per gram of MLSS per hour

$$\frac{\text{Oxygen uptake rate, mg/l/hr of oxygen} \times 1000 \text{ mg/g}}{\text{MLSS, mg/l}}$$

$$\frac{24 \text{ mg/l/hr} \times 1000 \text{ mg/g}}{2400 \text{ mg/l}} = 10 \text{ mg of oxygen/g of MLSS/hr}$$

The following Figures 4 and 5 present a standard format for recording respiration rate profiles and for graphing the results of such a profile.

FIGURE 4.

RESPIRATION RATE DATA SHEET

Date__________
Time__________
Sample Identification__________

Operator__________
Sample Temp.__________
Sample MLSS__________

St. #___	D.O.___	RR___		St. #___	D.O.___	RR___	St. #___	D.O.___	RR___	St. #___	D.O.___	RR___
Time - Min.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.
0												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

St. #___	D.O.___	RR___		St. #___	D.O.___	RR___	St. #___	D.O.___	RR___	St. #___	D.O.___	RR___
Time - Min.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.	Temp	D.O.	Δ D.O.
0												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Calculation: $$RR = \frac{(D.O._1 - D.O._2)}{t_2 - t_1} \times \frac{60 \text{ min}}{\text{hr.}} \div \text{MLSS, g/l}$$

Where $D.O._1$, $D.O._2$, t_1 and t_2 are beginning and end points of steady Δ D.O. and Δ D.O. is change in D.O. from previous measurement

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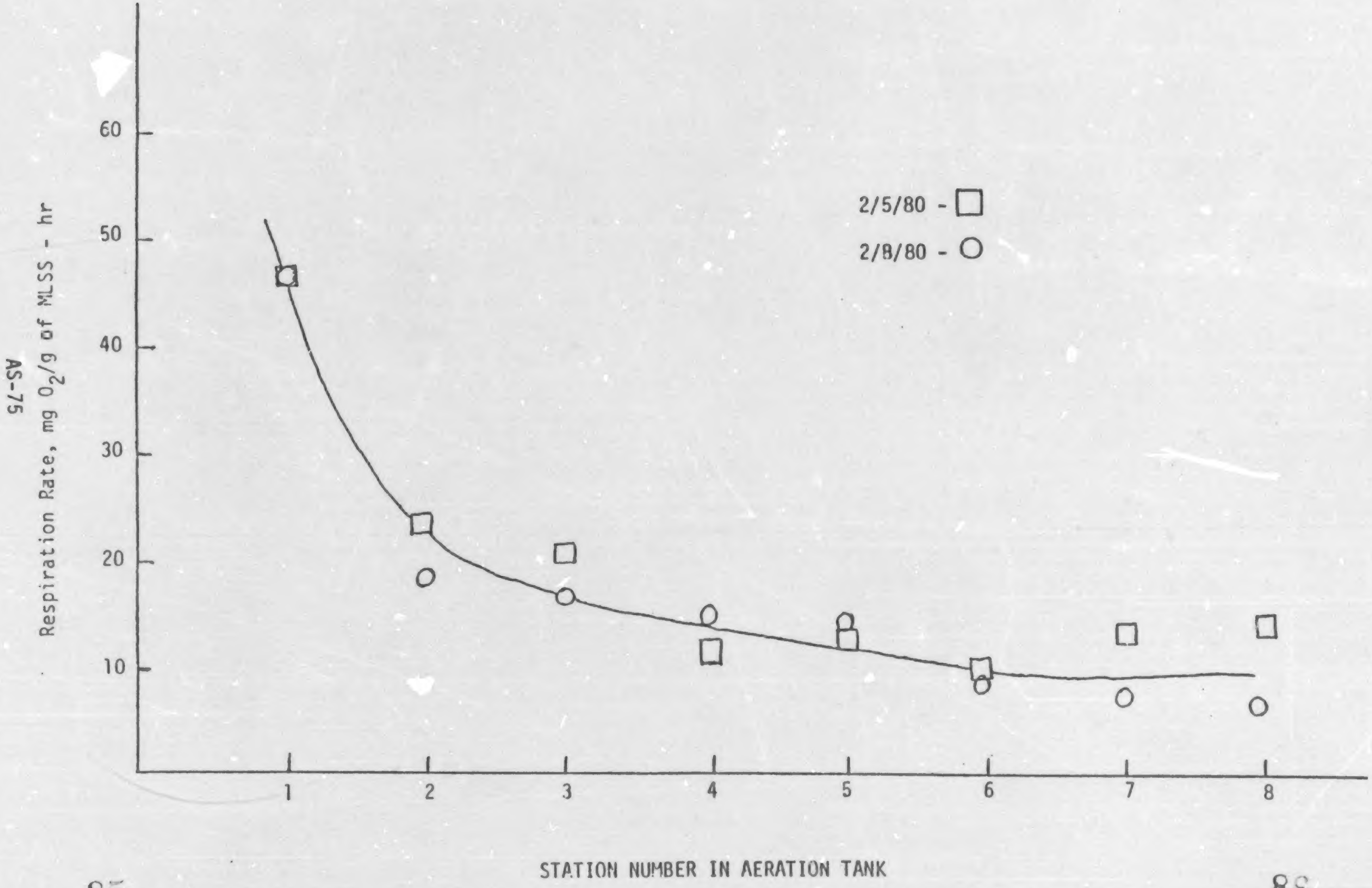
FIGURE 5.
RESPIRATION RATE PROFILE



Settleometer and Centrifuge Control:

A system has been developed and used by EPA and others to provide operators with a more timely indicator of the changing sludge quality. This system involves sludge settling tests and the observation of trends of the various process parameters. The main objective is to make determination of sludge quality a more timely activity. Figure 6 shows a representation of this interpretation which centers around settleability tests.

Settleability tests are conducted on samples of the mixed liquor collected in the aeration basin near the point of discharge to the secondary clarifier, and run in a standard Mallory Settleometer or similar container. Settleability tests are used to evaluate sludge settling characteristics, floc formation, and to provide information on return sludge rates.

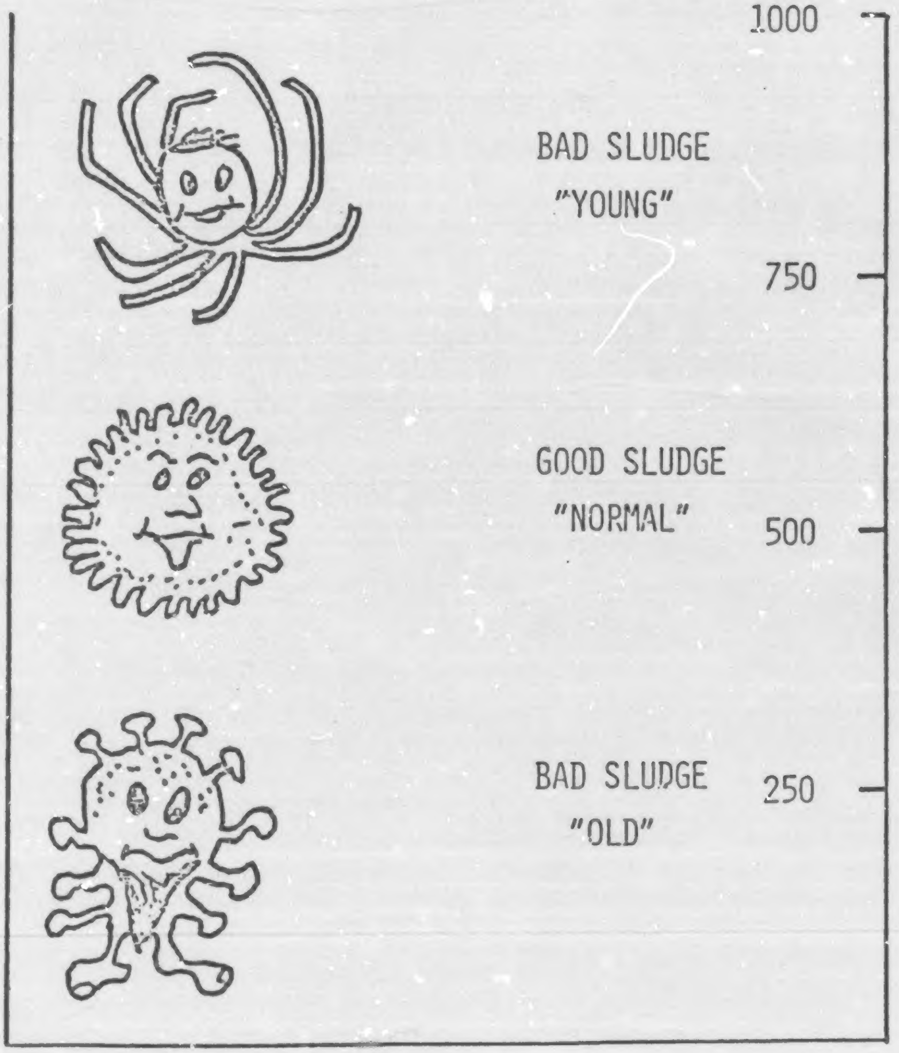
Centrifuge tests are conducted on the same samples from the aeration tank. A standard spin is a 15 minute spin at high RPM's. The information gained is the percent of volume of sludge when it is compacted to a great extent. It has been found, and can be readily shown, that under steady state conditions the spin tests can be reasonably correlated to a suspended solid test. Consequently, the centrifuge provides an operator with a relatively inexpensive tool for providing a very rapid determination of the solids concentration.

The settleometer is a key indicator for observing sludge quality. Diligent use of the settleometer can provide an experienced operator with days of advance warning of an impending disruption or change in process control. This advance warning provides the operator with valuable time to make appropriate process changes. The settleometer information can also be instrumental when recovering from an unavoidable operational upset. In this case, the advanced indicators can guide the operator through a series of process adjustments without wasting excess time waiting for the effluent results, or without trying to make a major adjustment in too short a time.

The first things an operator should look at when running the settleometer test are the floc formation and the blanket formation. Through experience, an operator will soon learn that within a few minutes he can detect certain characteristics which will describe the sludge quality. Is the floc granular,

FIGURE 6.

SLUDGE QUALITY


1000
BAD SLUDGE
"YOUNG"
750
GOOD SLUDGE
"NORMAL"
500
BAD SLUDGE
"OLD"
250

compact, fluffy or feathery? Does the floc settle individually or does it first form a blanket? Is the blanket ragged and lumpy, or uniform on the surface?

After the operator has looked at these characteristics, he then should observe settling rates and compaction characteristics. Is the blanket settling uniformly, or are segments settling faster than others? Is the sludge compacting and squeezing out water, or is it maintaining a constant density throughout? The operator should also realize how important a large diameter settleometer is in order to reduce the wall effects of a narrow cylinder. Many of these observations would not be noticeable in a 1000 ml graduated cylinder.

Observations such as these are important to the operator. They are not easily translated to numbers, so he should make appropriate notes on his data sheet for future references. There are, however, numerical observations which can be made. Figure 7 shows a typical data sheet which can be used to record appropriate sludge settling parameters. Observations and recordings are made every 5 minutes for the first half hour, and then every 10 minutes for the second half hour. More observations are made in the first half hour to ensure that the operator is taking the time to observe the floc formation and blanket characteristics. However, this can be modified to have readings taken at 5, 15, 30 and 60 minutes when normal sludge is present in the system. Additional readings may be necessary, including 90, 120 and 240 minutes for poorly settling sludges.

The settled sludge volume (SSV) and concentration (SSC) values by themselves are only partial tools. If these values are plotted on a graph as a function of time as shown in Figure 8, the shape of the curve that is plotted through these values defines the settling characteristics of the sludge.

A rapid settling sludge has a very steep initial settling and concentration profile. Sludge that exhibits this profile is usually one that exists under an environment of a low oxidation pressure, i.e., one that has a high MCRT and a low F/M.

FIGURE 7.

SETTLOMETER DATA SHEET

DATE____________________

DAY____________________

SAMPLE IDENTIFICATION______________________________

SSR = [1000-SSV30] 2

$SSC = \frac{ATC \times 1000}{SSV}$

Operator:

Time Of Test__________

Time	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		
	Time to Float	

ATC________

ATC________

RSC________

RSC________

DOB________

DOB________

TURB________

SSR________

Operator:

Time Of Test__________

Time	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		
	Time to Float	

ATC________

ATC________

RSC________

RSC________

DOB________

DOB________

TURB________

SSR________

Operator:

Time Of Test__________

Time	SSV CC/L	SSC %
0	1000	
5		
10		
15		
20		
25		
30		
40		
50		
60		
	Time to Float	

ATC________

ATC________

RSC________

RSC________

DOB________

DOB________

TURB________

SSR________

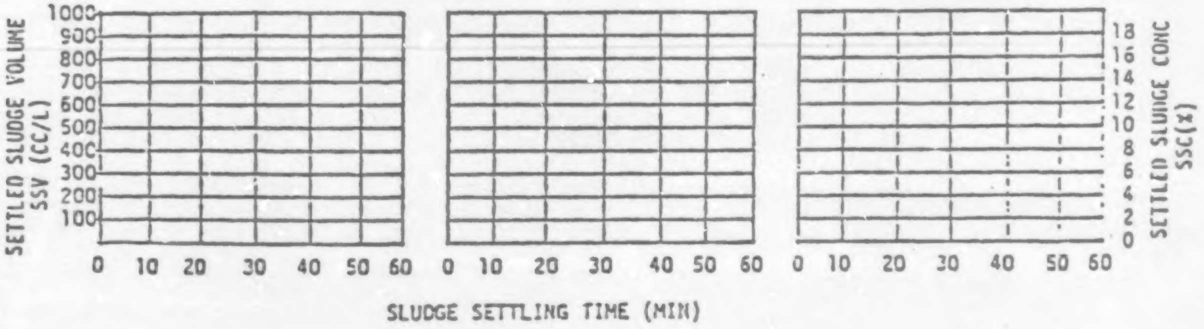


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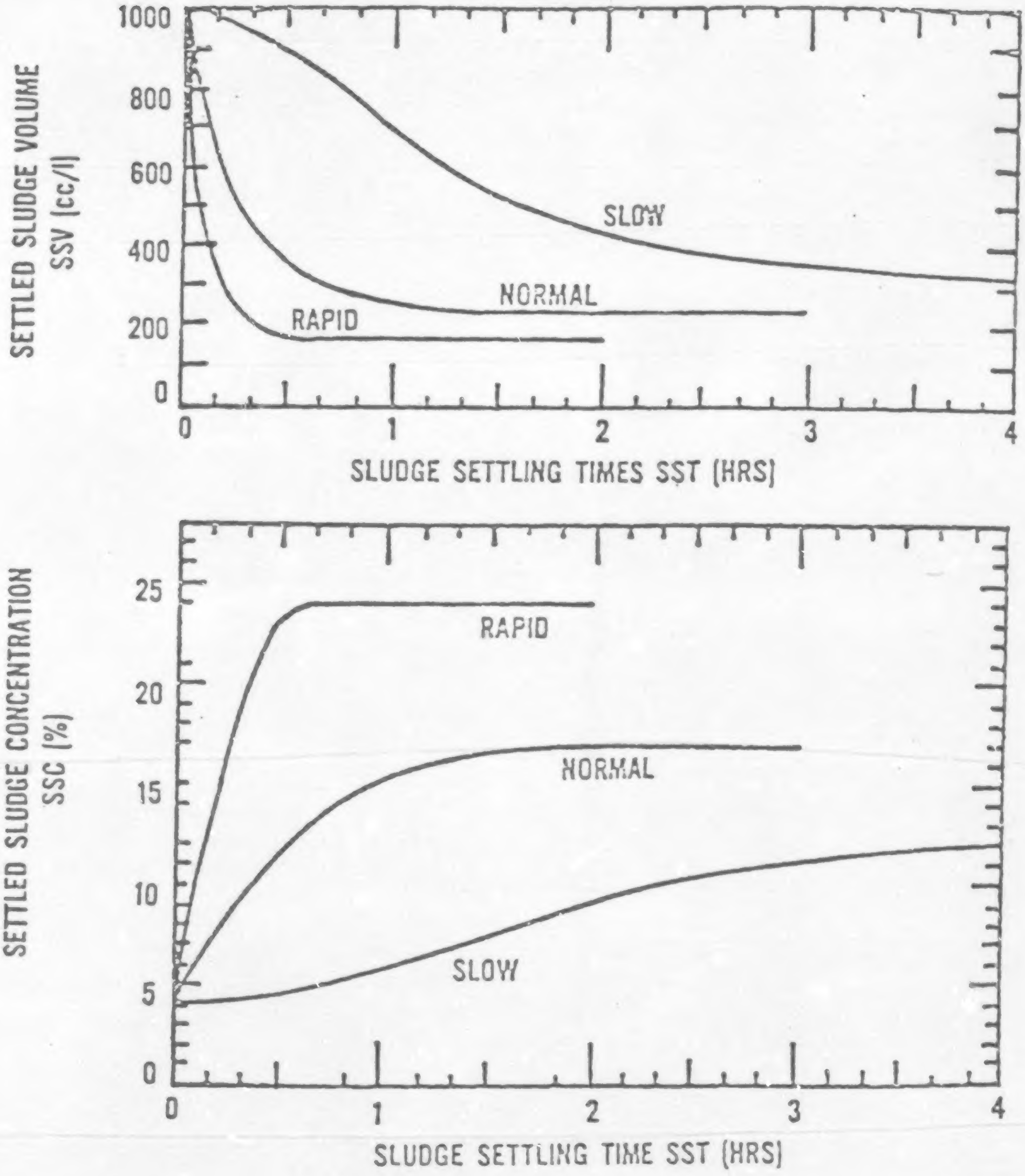
FIGURE 8.

SSV AND SSC CURVES FOR SLOW, NORMAL AND RAPID SETTLING AND CONCENTRATING ACTIVATED SLUDGES



A slow settling sludge has a very nominal settling and concentration profile. Sludge that exhibits this profile usually exists under a high oxidation pressure, i.e., a low MCRT and a high F/M. The extreme case of a slow settling profile is usually accompanied by massive proliferation of filamentous organisms.

The normal settling sludge represents the optimum state of sludge quality. Sludge with this profile is treating the optimum loading that will produce a high quality effluent with maximum stability in the process.

Analysis of data of an extended period of time provides a powerful tool for identifying trends in various components of the settling data. Many times one particular portion of the settling curve will change more dramatically than another. For the normal sludge three points on the settling curve, SSC_5, SSC_{30} and SSC_{60}, have been found to be the most sensitive. For a filamentous sludge, one that settles very slowly, you should at least add on SSC_{120} value.

The 5 minute SSC has been found to be a good indicator of the critical floc and blanket formation stage. The operator's observations and notes, however, are still very important for future reference.

The 30 minute SSC generally correlates to the settling test used in the sludge volume index measurement. Also, the majority of the settling should occur before the 30 minute reading, so that the distance settled reflects the settling rate of the sludge. For example, an SSV_{30} of only 600 would represent a very slow settling sludge.

The 60 minute SSC represents the level of compaction that can be expected from a "normal" sludge. This concentration, therefore, relates to the return sludge concentration that is actually observed in the plant. These numbers will seldom be the same due to flow characteristics and other physical differences found in the clarifiers. The important criterion, however, is that the settleometer characteristics are reproducible for similar sludge quality characteristics.

Figure 9 is an example of a trend plot of several days of settleability data. This example shows the changes of sludge settleability from a fast sludge to a normal sludge.

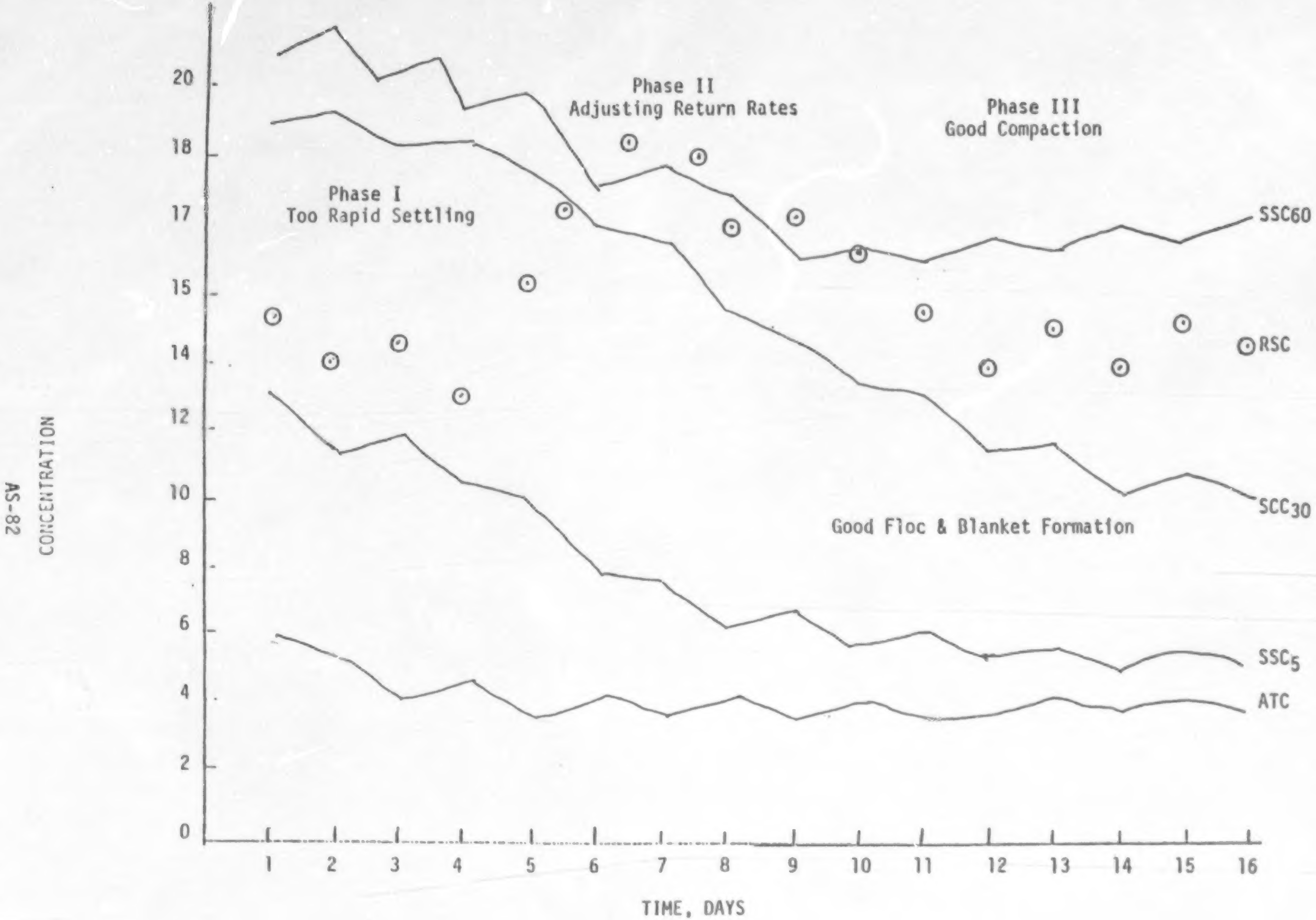

AS-82
CONCENTRATION
20
18
17
15
14
12
10
8
6
4
2
0
Phase I
Too Rapid Settling
Phase II
Adjusting Return Rates
Phase III
Good Compaction
SSC60
RSC
SCC30
Good Floc & Blanket Formation
SSC5
ATC
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TIME, DAYS

FIGURE 9

Sludge Volume Index (SVI)

SVI is a classic measure of sludge quality which is the ability of the organisms to flocculate and settle efficiently, leaving a solution with low turbidity.

Example:

30 min. settleable solids from mixed liquor channel = 280 ml/l

MLSS from mixed liquor channel = 2750 mg/l

Calculation of SVI:

$$\text{SVI, ml/g} = \frac{\text{30-min. settleable solids, ml/l} \times \text{1000 mg/g}}{\text{MLSS, mg/l}}$$

$$= \frac{\text{280 ml/l} \times \text{1000 mg/g}}{\text{2750 mg/l}}$$

$$= \text{102 ml/mg}$$

Usually the settleable solids test is carried out in a 1000 ml graduated cylinder. A better method is to use a Mallory settleometer or a 2-liter battery jar which has a larger diameter than the 1000 ml graduated cylinder and thus decrease side-wall effects. The major limitation of the SVI is that it only examines one point on the settling curve. Other data which may be indicative of process changes may be missed.

Microscopic Examination:

Microscopic examination of the activated sludge on a regular basis is another means of evaluating the process conditions. These results should be used in conjunction with the other process control tests described earlier when making process decisions. Samples of mixed liquor from the aeration tanks should be examined individually according to the following.

A sample of mixed liquor is thoroughly mixed with gentle agitation as soon as possible after sampling. Vigorous mixing will disperse the floc. Using a micropipet, place a 50 micro-liter sample on a slide and cover the sample with a No. 1, 22 x 30 coverglass. The entire sample should remain under the coverglass and the floc should be evenly distributed.

The slide is counted with a phase contrast scope at 100x. Only one pass is counted across the center of the slide (left and right). All organisms encountered are tallied (protozoans and filamentous bacteria). The protozoans are counted by major groups: (a) flagellates, (b) amoebas, (c) ciliates (stalked and free swimming), (d) rotifers, (e) worms. If required, these groups may also be tallied by genus; for example, free swimming ciliates: (a) lionatus, (b) paramecium, (c) aspidisca, etc. This latter type of tallying is generally not necessary.

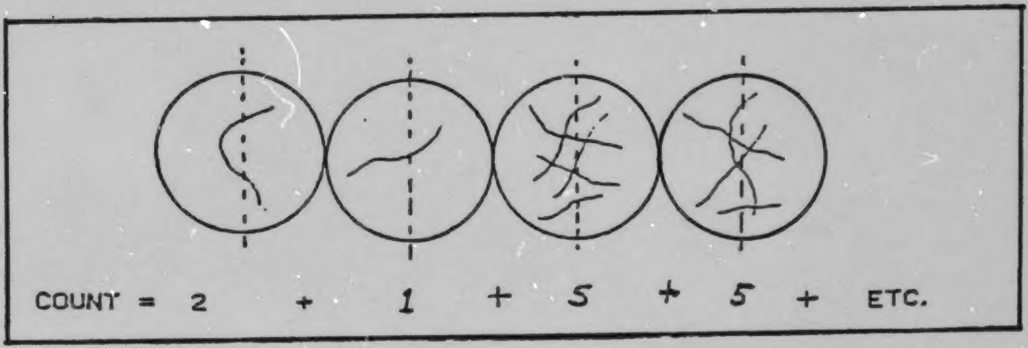
It is not practically possible to count filamentous organisms as individuals nor is it possible in most cases to determine the genus. However, most important from an operational viewpoint is the ability to obtain a meaningful measure of the number of filamentous organisms present. This may be accomplished by using a count which is proportional to the number of filaments present. A good method for determining this is to count the number of times filaments are crossed by a line through the center of the microscope field from top to bottom. A tally of the total width of the slide is made by counting tangential fields as shown in Figure 10. The total filament count is the sum of the separate field counts across the slide horizontally. The final result may be expressed either as the number of filamentous organisms counted per horizontal pass, or better this result may be converted to the number of filaments per microliter. The latter value which allows for a broader comparison of data may be calculated by multiplying the total count per horizontal pass by a factor F (i.e., number of filaments/ul = count per pass X F), where F = number of fields needed to cross the slide vertically ÷ 50.

A comparison of the filament count with SVI is shown in Figure 11. These data, along with more recent information, have shown a close correlation between filament counts and SVI. The photo micrographs of actual filamentous sludge in Figure 12 show how certain filament counts appear and their relation to SVI.

An example of the worksheet used for the microscopic examination of activated sludge is given in Figure 13.

FIGURE 10.

FILAMENT COUNTING TECHNIQUE


COUNT = 2 + 1 + 5 + 5 + ETC.

AS-86

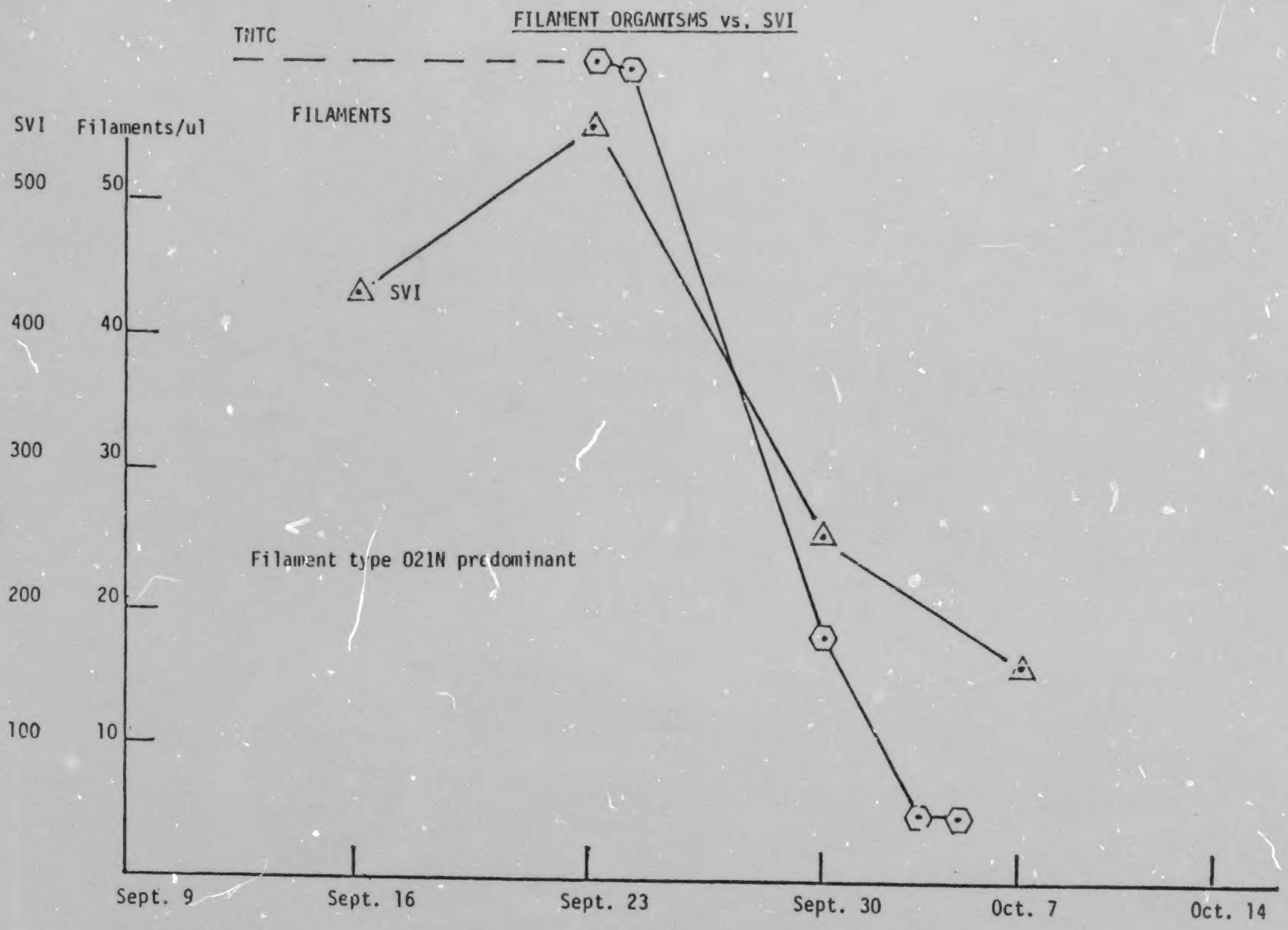
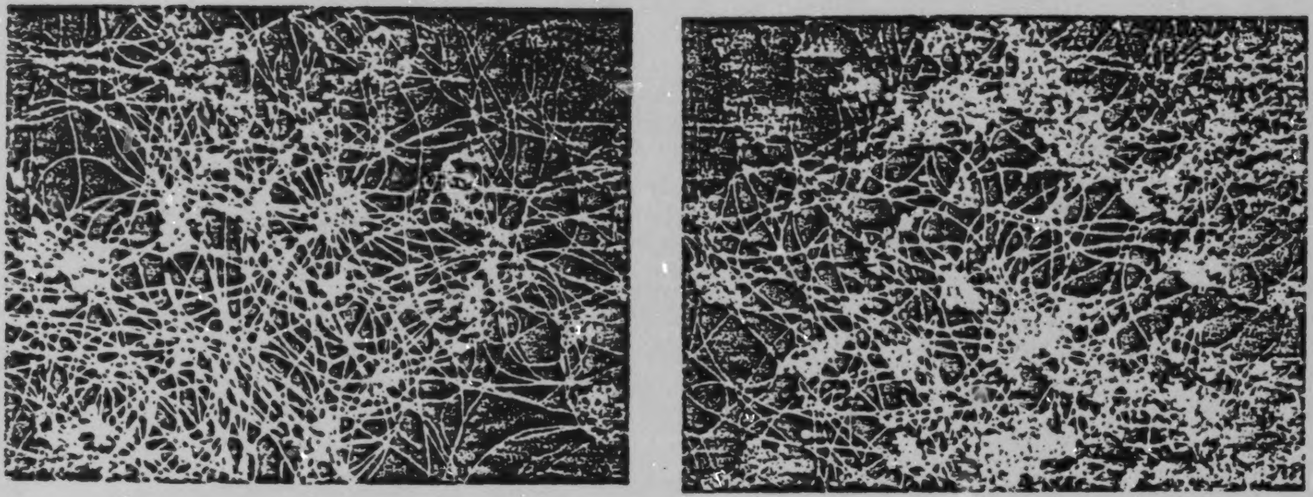


FIGURE 11

FIGURE 12.

FILAMENTOUS SLUDGE RELATED TO

FILAMENT COUNT AND SVI



9/16/79 (Jelly characteristics
insludge)

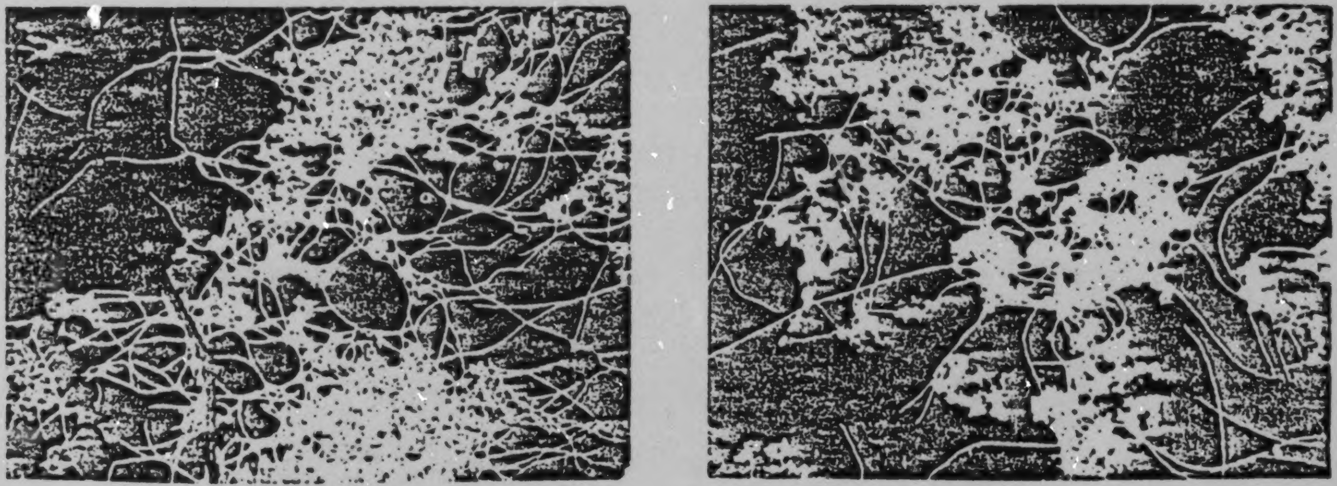
Avg. SVI of 431

Filaments TNTC

9/23/79

Avg. SVI of 562

Filament count of 61/ul



9/30/79

Avg. SVI of 251

Filament count of 18/ul

10/5/79

Avg. SVI of 167

Filament count of 5/ul

FIGURE 13.

WORKSHEET FOR MICROSCOPIC EXAMINATION OF ACTIVATED SLUDGE

Date:________ to ________

Sample Location and Time:______________________________ By:________________________

MICROORGANISMS \ DATE								AVERAGE
AMOEBOIDS								
FLAGELLATES								
FREE SWIMMING CILIATES								
STALKED CILIATES								
ROTIFERS								
FILAMENTS								
OTHER								

DATE:	COMMENTS

Oxidation State of the Biomass:

The preceding lessons have defined various tools and parameters that can be used in monitoring the quality of the activated sludge. In many circumstances any one of these tools can provide a competent operator with enough knowledge to adequately operate his system. However, there are some risks. If conditions change, if he leaves, if a new industry comes to town, if the plant is modified, then his experiences using only one tool may not be sufficient. A good operational program will use several tools. The information from these tools will be factored into a determination of the state of sludge quality which is the oxidation state of the sludge. Figures 14 and 15 show how some of these factors will tilt the oxidation scale towards either an over-oxidized sludge or an under-oxidized sludge.

FIGURE 14. OXIDATION PRESSURE INDICATORS

INDICATORS	INDICATORS
STRAGGLER FLOC	PIN FLOC
HIGH TURBIDITY IN EFF.	LOW TURBIDITY IN EFF.
WHITE, FLUFFY FOAM	DARK, SCUMMY FOAM
SLOW SETTLING	RAPID SETTLING
HIGH SVI	LOW SVI
HIGH RR	LOW RR
CLASSICAL FILAMENTS	NOCARDIA FILAMENTS

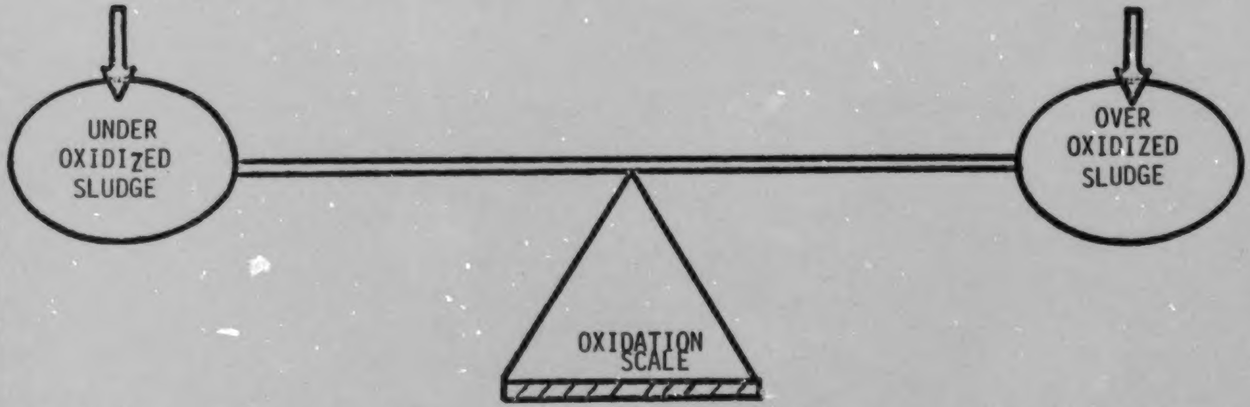
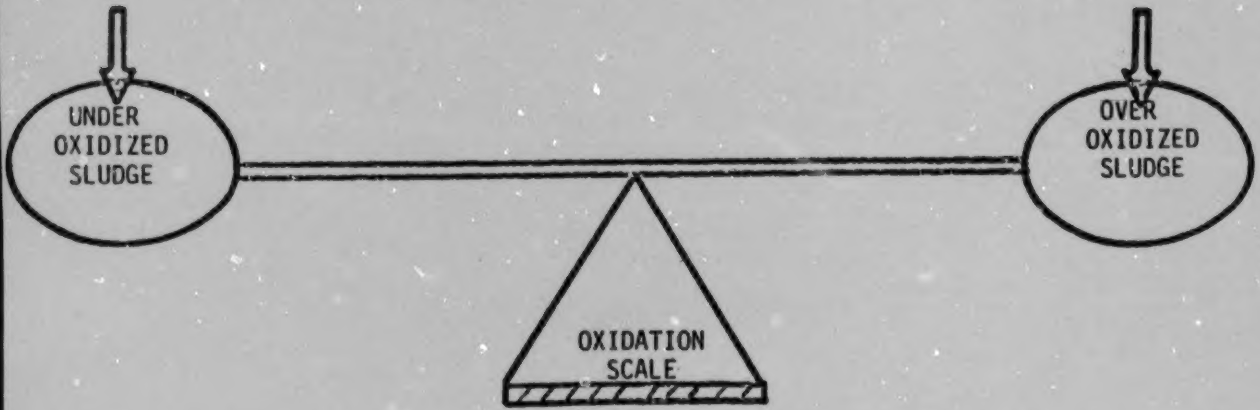

UNDER OXIDIZED SLUDGE
OVER OXIDIZED SLUDGE
OXIDATION SCALE

FIGURE 15. OXIDATION PRESSURE FORCES

FORCES	FORCES
HIGH F/M	LOW F/M
LOW MCRT, CRT, SLUDGE AGE	HIGH MCRT, CRT
LOW D.O.	HIGH D.O.
LOW MLSS	HIGH MLSS


UNDER OXIDIZED SLUDGE
OVER OXIDIZED SLUDGE
OXIDATION SCALE

RESPIROMETRY FOR PROCESS CONTROL

What is Respirometry?

Wastewater treatment in aerobic biological systems is based on the ability of microorganisms to utilize dissolved oxygen in breaking down organic materials. The rate of oxygen uptake is commonly referred to as respiration rate. "Respirometry" refers to the measurement of respiration rate (oxygen consumption).

Metabolism - Aerobic, Facultative and Aerobic

As a general rule, "bugs" (microorganisms) consume oxygen in proportion to the amount of biodegradable organic material available to them. They sustain themselves by breaking down complex materials to get energy (catabolism) and by using that energy to build new cell mass (anabolism). The sum total of all the catabolic and anabolic reactions is called metabolism. A key ingredient in this process, of course, is oxygen. Aerobic bugs require free oxygen to carry out their metabolic processes. When oxygen is not available, aerobic metabolism ceases, and bugs capable of living in the absence of oxygen are stimulated to grow. Bacterial metabolism continues, but the types of bacteria and end products are different. Bacteria requiring the absence of free oxygen are called "anaerobic", while those capable of living with or without free oxygen are called "facultative". Our discussion and use of respiration rate measurements deals with aerobic and facultative bacteria.

B.O.D. - Biochemical Oxygen Demand

Examples of aerobic wastewater treatment processes include: activated sludge, trickling filtration, RBC, ABF, and lagoons. In each case, organic material is removed from the wastewater by microorganisms, and in the process, tremendous quantities of oxygen are consumed. Biodegradable organic material (food) sustains bacterial metabolism, and as long as sufficient oxygen is present, the bugs eat and reproduce. Oxygen is consumed by the bugs at different rates, depending on how much food is available to them. Sometimes we use the term B.O.D., biochemical oxygen demand, in referring to the "organic strength" of a waste. Simply stated, the more organic material the bugs see, the more oxygen they demand biochemically in breaking it down. This idea, then, of using "oxygen demand" as an indicator of organic strength has been with us for many years. The B.O.D. test may be called a "bioassay" because measurements are being made by a biological system. We ask the bugs to tell us, by measuring a depletion in oxygen, what the oxygen demand of a particular waste might be. As a general rule, we give the bugs 5 days to metabolize at a relatively slow rate. Oxygen depletion stops when the bugs run out of food. Of course, we had better have enough oxygen in the bottle to start with at the beginning of our 5-day test, or the bugs will suffocate before all of the food is used up. In order to assure that we have enough oxygen for 5 days, we limit the amount of food (BOD) that is placed in the bottle by diluting the waste, and then back-calculate what the oxygen consumption would have been if the waste had been full-strength. The B.O.D. test is often cursed by operators because of the 5-day time lapse. By the time we know the strength of the waste in the influent, it is long gone down the river. Using influent B.O.D. data for process control decisions, therefore, is difficult.

Is there another way of asking the bugs to tell us how much food is present, i.e., "Where's the beef"? The principle of oxygen consumption over a period of time serves as the basis for bioassays utilizing "accelerated B.O.D." measurements, and we use an instrument called a respirometer to supply a known quantity of oxygen to a high concentration of microorganisms, and measure the rate that oxygen is consumed as the bugs stabilize the biodegradable organic materials that they are fed. The oxygen uptake rate correlates directly with the amount of available food, and when the food (B.O.D.) has been exhausted, the microorganisms resume a relatively low, steady rate of oxygen consumption that is called the "endogenous" respiration rate. As long as the microorganisms are alive, they breathe oxygen to maintain their basal metabolic (endogenous) requirements. The presence of any biodegradable organics raises their uptake rate above their endogenous rate in a direct relationship to the amount of B.O.D. available. It becomes a simple task, then, to determine the endogenous respiration rate of a biomass, and then feed these bugs. If continuous oxygen uptake measurements are taken over a long enough time period (several hours), the recorded data describes the oxygen demand of that particular "feeding" and the time period necessary for the bugs to stabilize the waste and return to their endogenous respiration rate - our assurance that the applied B.O.D. has been removed.

Uses of Oxygen Uptake Information:

Predicting Organic Load, Adjusting Air

Process control managers hope to accurately anticipate changing conditions soon enough to make adjustments necessary to maintain (or establish) equilibrium in the treatment plant. Flows and loadings may vary throughout the 24-hour day. Most plants are designed with a certain degree of "stretch" which allows them to accommodate a range of operating conditions without significantly impacting performance. Tankage and aeration capacity are several of the components that provide the plant's ability to "stretch". In an attempt to satisfy peak oxygen demands, we often are forced to over-aerate during periods of lower loadings. Obviously, matching air discharge with oxygen uptake may result in energy savings. This assumes, of course, that a rapid and reliable means exists to anticipate oxygen demand. The respirometer is just such an instrument.

Sludge quality may be negatively affected by either too little air, or too much. Oxygen availability and aeration detention time are significant growth pressures. They govern, to some degree, what type of bugs predominate in a system and how efficiently they remove dissolved and suspended material from the wastewater. A great deal of attention is given to the settling characteristics of biological sludges - and rightly so! The critical part of biological treatment shows up in the secondary clarifier, where liquid/solids separation occurs. The efficiency of a secondary clarifier is influenced primarily by three elements: (1) plant hydraulics; (2) clarifier design; (3) sludge quality. Plant hydraulics and clarifier design may be out of our control, but sludge quality responds to the growth pressures imposed on the bugs by the decisions of the process control manager. We are interested, then, in accommodating the biological needs of a system because it affects sludge settleability.

Aeration Detention Time - How Much is Enough?

Most of the biological work accomplished in secondary treatment occurs in the aeration basin (biological reactor). The aeration basin is also one of the most expensive parts of a plant to operate because of the energy required for aeration. Aeration time that is too short causesobvious problems of poor B.O.D. removal because the bugs just don't have enough time to eat all the food and create stable end products. On the other hand, long aeration times may be a problem if the bugs starve too long because the population and floc structure changes. "Ashing" and "pin-floc" are terms that are commonly used to describe the effects of over-aeration. Floc seems to disintegrate to some degree, becoming more granular and rapidly settling. As this type of sludge settles, it leaves behind small particles which create turbidity and accummulate on the surface as a thin film of "ash". Aeration detention time should be long enough to allow for good B.O.D. removal and stabilization, but short enough to prevent floc deterioration and excessive "ashing". There are times when long detention times are intentionally targeted, particularly when nitrification is a treatment objective. A potential exists for denitrification in the sludge blanket of the secondary clarifier, demanding increased operator surveillance.

The question of aeration detention time is a complex one and must be answered with the treatment objectives well in mind. Do we want to nitrify or not? How is sludge yield affected by changing detention time? What are the energy consequences of the operating targets? Oxygen uptake information does not reveal a complete picture but does provide several valuable pieces in putting the oeprational puzzle together.

Toxicity - Determine and Predict Impact

The term "toxicity" is used in referring to those cases in which a waste causes microbial death or metabolic impairment, resulting in a biological upset and reduced treatment efficiency. Potentially toxic materials exist in every community, and the likelihood of them entering the wastewater system at one time or another is a sure bet. Whether or not they cause a noticeable impact on plant performance depends on what they are and how much is present. Industrial wastes oftentimes represent an even greater challenge to plant operators. Sewer use ordinances attempt to accommodate an industry's needs to dispose of their wastes while protecting the treatment plant's needs to operate in compliance with their discharge permit. Fees are charged for treating wastes in an attempt to cover the costs and impact of each user. Process control managers are faced with a difficult task when the time comes to develop a strategy to deal with toxic wastes. Respirometry can be a tremendous ally in sorting out the biological questions of treatability and could be used as one of the cornerstones in an equitable sewer use ordinance.

Getting back to the basic work of an aerobic treatment system, bugs are fed a waste, they eat it and consume oxygen as they stabilize it. The uptake of oxygen parallels the removal of B.O.D. Toxic materials inhibit normal respiration. The rate of oxygen uptake is lower than normal, and consequently, the rate of B.O.D. removal (treatment efficiency) is lower than normal. It sounds straightforward, and it is. If we have laboratory data which accurately describes the "normal" respiration rate of our bugs, it is not difficult to see the degree to which a suspected waste is inhibitory.

Toxicity may be so serious that the bugs' respiration rate not only slows down, but it stops altogether. B.O.D. removal, predictably, stops as well. The bugs die, and the floc structure deteriorates. Sludge deflocculates, releasing high suspended solids. Plant performance is poor. Effluent may be higher in B.O.D. and suspended solids than the influent. This is an extreme example of a toxic impact - but a very real possibility in an exposed system.

Whether toxic wastes simply slow down the treatment process or stop it altogether, we have to know how our bugs "feel" about what they are being fed if we hope to maximize treatment efficiency. The bugs, of course, are always willing to tell us how they "feel" by letting us listen to their "breathing". The respirometer, therefore, becomes a "toximeter" when it is used to evaluate the treatability of a suspected toxic waste. If we want to ask the bugs if they can handle it in different concentrations, simply re-run the respirometer with any concentration and mixture you've wondered about. Amazing insight into industrial monitoring and control awaits those who "let the bugs do the talking".

Modelling the Variables - MLSS, Temperature, Nutrients, pH, F/M

Each treatment plant is a unique biological experiment - a specialized community of microorganisms which thrive because of the design, loading and applied operating pressures. With the addition of a little bit of luck, the bugs stay healthy and happy, operating targets are met, and plant performance meets permit. Most textbooks provide guidance in setting operating targets, and it may be reassuring to shoot for a particular F/M because the experts who wrote the book believe in it, but there are no guarantees that the bugs will do what the books say. Bugs can't read. Bugs can't talk. We pose questions to the bugs by varying MLSS concentration, nutrient balance, temperature, pH, or anything else that may have an effect on their metabolic rate, and then we listen for the answers by recording the respiration rate of the "test conditions".

Operating conditions change considerably from one season to another. Temperatures may warm up in the summer, flows may change, organic loading may be different, and so on. We often ask each other - should we increase or decrease mixed liquor concentration? Should we take an aeration tank off line, or do we need it? If the water warms up 6 degrees, what effect will it have on our aeration time requirements? What is the effect of digester supernatant on the secondary system? These are but a few of the many questions that beg for answers. Why not ask the bugs? It is simple to run the respirometer at practically any MLSS concentration in which we are interested. If the bugs stabilize the applied waste load at a different rate, it can be clearly shown. Some respirometers allow for temperature control. This lets us ask the bugs what effect changing temperatures have on their rates of respiration. The possibility of communicating with the bugs is limited only by the imagination of the operators using the respirometer.

It is important to remember, though, that "modelling" a system be done only after we thoroughly understand what is "normal" for our plant and our bugs. There are no textbook numbers that can reliably substitute for the background data needed to accurately describe the biological status of a treatment system. What is normal for one plant may not be normal for another. "Normal" exists, however, for each and every plant. Once we've developed a reliable respirometric data base, we need apply only good experimental design in modelling the system to provide greater operational insight and achieve a degree of "anticipatory process control".

Oxygen uptake measurements may be accomplished simply with a D.O. meter and a B.O.D. bottle, or you may use a recording respirometer. Whatever the method, the importance of the information is the same - and that is the fact that a direct communication link is set up between the bugs and the operator. A respirometer is no more essential in running a plant than radar is required when flying an airplane. But the technology exists, it provides tremendous insight, and is one of the process control tests that should be considered as we go beyond "seat of the pants" operations.

Lesson 5: Return Sludge Control

Return sludge control has been previously identified as one of the three major control parameters of the activated sludge process. The main objective of return sludge control is fairly obvious. That is, to return solids (biomass) that has separated and settled in the clarifiers back to the aeration tanks. As simple as that sounds, that control feature provides for an incredible amount of process flexibility. Ardern and Lockett discovered this advantage almost sixty years ago when they returned the "flocculated" solids back to the aeration tank and produced a better effluent quality in their experiments. They, and many others since, have discovered that returning settled sludge provides the ability to maintain biomass in the system longer than the hydraulic (sewage) detention time. This phenomena allows designers to build aeration tanks that have a six hour detention instead of a six day detention time which obviously results in considerably less expensive treatment plants.

A second objective of return sludge control is to optimize the clarifier operation. This optimization process has two distinct variables. The first is the effluent quality and the second is the energy consumption. The effluent quality is a fairly obvious goal because the ultimate test of success is whether we remove the biomass from the effluent or let the biomass go to the river. If we were to let the biomass go to the river, then we would need to reconsider the advantage of secondary treatment.

The second variable of clarifier optimization was identified as energy control. The return pumps are one of the bigger energy users in most treatment plants. Non-control from an energy standpoint could easily increase an electric bill by ten percent.

Clarifier Theory

It is important to understand clarifier theory if we are to meet the objectives of returning biomass to the aeration tanks and of optimizing clarifier operation.

The first principle of clarifier operation is that solids have a greater density than water and, therefore, settle.

The settling velocity, however, does not have to be very large. For example:

If: Hindered settling rate = 0.025 cm/sec

Then: Required overflow velocity = 8.2×10^{-4} ft/sec

= 9.5 gal./day/ft^2

Many clarifiers are designed at 100 times this amount to capture discrete particles or the small straggler floc.

If the settling velocity of the discrete solids are known, then we can conclude that the overflow velocity or the rise velocity has to be less than the velocity of the smallest particle we want removed. This relationship is shown in Figure 1. If we know the overflow rate, then we can also calculate the area of the clarifier as shown in the following:

$Q=VA$ or $A=\frac{Q}{V}$

When: V= velocity (ft/sec)

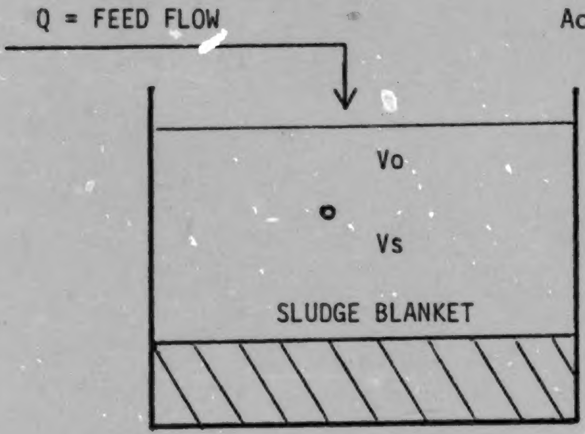
Q= flow (ft^3/sec)

A= area (ft^2)

There is a second principle acting on the clarifier also shown in Figure 1 which regulates the area of the clarifier. Since we defined earlier that energy conservation was one of our objectives of clarifier operation, we need to have thickened biomass in order to reduce pumping requirements. The area required for thickening

FIGURE 1. DESIGN CONSIDERATIONS OF FINAL CLARIFIERS

1.0 AREA REQUIRED FOR CLARIFICATION [Ac]


Q = FEED FLOW
Vo
Vs
SLUDGE BLANKET

$Ac = Q/Vs$

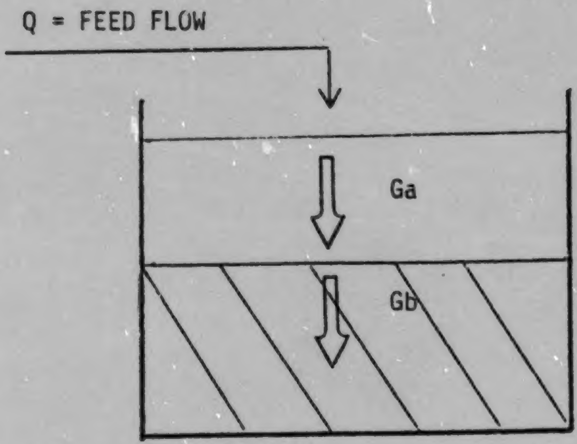
WHERE:

Vo = rise or overflow velocity

Vs = settling velocity of discrete particle

2.0 AREA REQUIRED FOR THICKENING [At]

$$At = \frac{(1\ tr)\ Q\ MLSS}{Gl}$$


Q = FEED FLOW
Ga
Gb

WHERE:

Gl = clarifier limiting flux

Ga = applied flux

Gb = blanket transfer flux

is "that which assures that the applied flux does not exceed the solids transmitting capacity of any layer of sludge that may exist in the final settling tank". This is a complicated way of saying that the solids loading to the clarifier can not exceed the ability to move the thickened sludge (sludge blanket) to the return pipe. The term flux is an engineering term which describes the rate of solids moved through one square foot of clarifier area. The applied flux (Ga) is then the pounds of biomass loaded to each square foot of the clarifier per day or lbs/day/ft^2 of clarifier surface.

Dick has reported that a batch settling test will provide the information needed to determine the maximum or limiting flux (Gl) that can be applied to a clarifier. When Gl is found (Figure 2), then the clarifier area can be calculated as follows:

$$Al = \frac{(1 + r)\ Q\ MLSS}{Gl}$$

Since operators are more interested in calculating their return rate instead of the design area, this equation can be manipulated to find the return rate for a given flux. This is shown in the following equation where R = percent return flow.

$$R = \left[\frac{A\ Gl}{Q \times MLSS} - 1 \right] \times 100$$

Example:

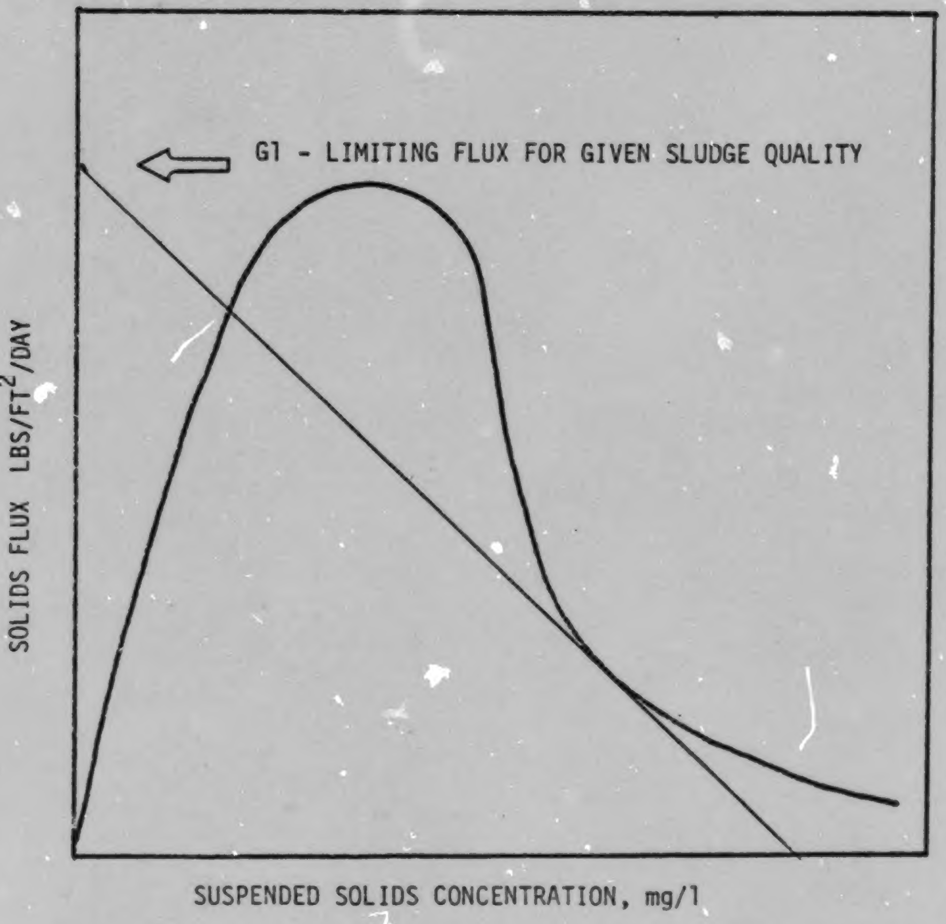
Area: A = 10,000 ft^2

Flux: G = 15 lbs/day/ft^2

Flow: Q = 5 MGD

MLSS - 2500 mg/l

FIGURE 2. IDENTIFICATION OF LIMITING FLUX FROM BATCH SETTLING TESTS (AFTER DICK)



Then:

R= 40% (or 2MGD)
ration of return to plant flow is r= R/Q

r= .4

We can also find an equation which relates return sludge flow (RSF) to the return sludge concentration (RSC). Taking a mass balance on the aeration tank we find:

$$RSC = \frac{Q\ MLSS\ (1 + r)}{r}$$

Example:

MLSS = 2500 mg/l

r= 0.4

RSC = 8750 mg/l

Classical Return Sludge Flow Determinations

Definitions:

CSFD= Clarifier Sludge Flow Demand (MGD)

RSF= Return Sludge Flow (MGD)

RSC= Return Sludge Concentration (mg/l)

MLSS= Mixed Liquor Suspended Solids (mg/l)

Q = Secondary Feed Flow (MGD)

The procedure described previously is cumbersome and not very useful for process control. Operations literature has defined several other methods to determine return rates. It should be pointed out, however, that these procedures are for plug flow or for complete mix systems. Step feed systems require some different considerations that are not addressed here.

Desired MLSS

$$RSF = \frac{MLSS \times Q}{RSC - MLSS}$$

This procedure works on three important assumptions: (1) the operator knows what MLSS level he wants to hold, (2) the return sludge concentration will remain constant, and (3) the clarifier has an excess of solids at a concentration of RSC. The first may be true, the second and third are often not true. RSC depends on the sludge quality and clarified inventory changes as the depth of the blanket in the clarifier changes with plant flow. In most cases, it is best to assume and to operate as if there is a minimum amount of solids in the clarifier, not an excess. The notion that there is a surplus of solids in the clarifier that can be brought out at any moments notice has caused many an operator or engineer embarrassing problems at some point in time. Used in the proper context, however, this procedure provides an easy tool for managing return sludge control.

Clarified Sludge Flow Demand

$$CSFD = \frac{RSF \times (RSC - MLSS)}{RSC - MLSS}$$

This concept was defined by Al West and also makes three critical assumptions. The first is that the clarifier is at equilibrium, i.e. the solids inventory in the clarifier is not changing at the time of analysis. Secondly, when a new return flow (CSFD) is achieved, a new return sludge concentration (RSC) will be achieved and will be directly proportioned to the change in flow. Thirdly, the MLSS will not change during this return change. For small and frequent changes in the return rate, these assumptions are generally valid.

The selection of the desired return sludge concentration can be concluded from experience and from settling tests and will be discussed further in the following sections.

SVI Determination of RSF

The return rate can be based on settleability of sludge as described by the SVI test.

$$RSF = \frac{Q \times MLSS}{10^6/SVI - MLSS}$$

This procedure is very similar to the West procedure except that the use of SVI predetermines the desired goal of the return sludge concentration, i.e. RSC equal the sludge concentration after thirty minutes of settling. The same considerations as identified in West procedure should be evaluated before control decisions are made.

Fixed Rate of Flow

A fixed return rate works fine in many plants. Generally, these plants are all over designed or underloaded and changes in the return rate are not warranted to improve effluent quality. The energy demand may not be optimum, but then the manpower may be a more costly feature if frequent changes in return rates are practiced.

Percent Return Rate

Relying on a fixed percent return rate provides an easy mechanism to manage return sludge control. This procedure, however, does not provide any immediate mechanism for establishing the given set point. Experience is a leading factor for settling a present return rate as well as the previously discussed methods. One risk in this control method is that it removes the result from any direct line of feedback of information. If plant conditions or the sludge quality changes, then a new set point would need to be determined.

Sludge Quality Based Return Sludge Control

When a plant is manned with permanent operators for one, two or three shifts and if the plant receives a changing flow of 50 to 150% from maximum to minimum, and if the plant is conventionally loaded, then it is usually productive to check and to change return sludge flows at least once per shift. The procedure that will be described in the following section is derived from the Al West control procedures, but stops short of calculating "flow demands." These procedures are easy to apply and rely on establishing historical patterns through the use of trend charts to determine if the assumptions are appropriate for a specific plant and a specific sludge quality. These procedures can be used to provide the back-up support when any classical control procedure is used. These procedures and analyses provide a rational basis for changing return rates when stress conditions develop, and, therefore are helpful for any control plan.

The information needed for eeveloping a sludge quality based return sludge control program is from centrifuge and settleometer data. The following definitions and assumptions are provided for completing the program.

Definitions:

1. SSC: Settled Sludge Concentration

   A concentration value calculated from the settleometer data (see Figure 3) and is referenced to a specific time, i.e., SSC_{30} is the concentration of sludge after 30 minutes of settling.

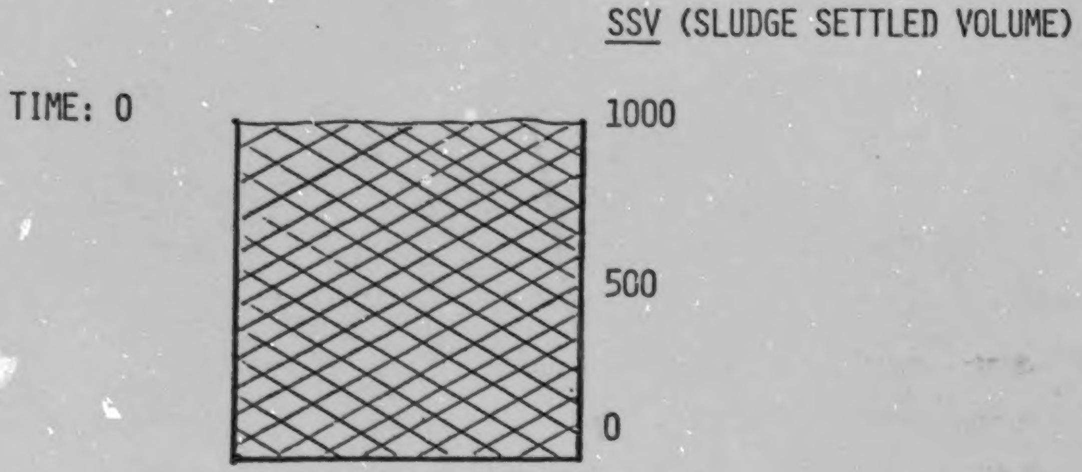
2. SSV: Settled Sludge Volume

   A volume of sludge measured in the settleometer at a given time. Figure 4 is a sample work sheet for recording that data.

3. ATC: Aeration Tank Concentration

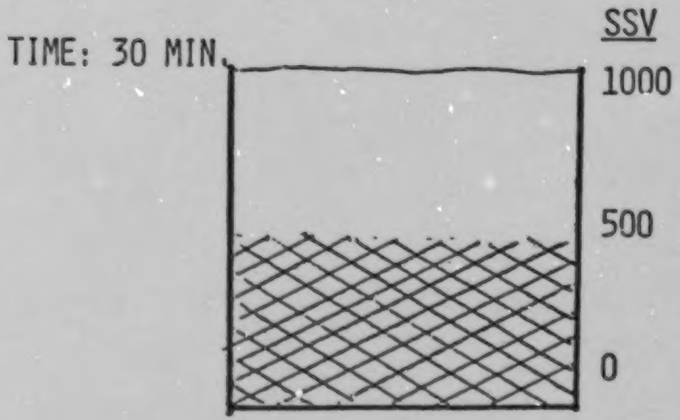
   The concentration of mixed liquor, expressed as percent by volume, and measured by the centrifuge.

Figure 3. SLUDGE SETTLED CONCENTRATION (SSC)


SSV (SLUDGE SETTLED VOLUME)
TIME: 0
1000
500
0

CONCENTRATION = AERATION TANK CONCENTRATION (ATC)

SSC = ATC = 3%


SSV
TIME: 30 MIN.
1000
500
0

CONCENTRATION: IS IN 1/2 OF ORIGINAL VOLUME
THEREFORE IS TWICE AS CONCENTRATED

$$SSC = \frac{ATC \times 1000}{SSV} = \frac{3\% \times 1000}{500} = 6\%$$

FIGURE 4.

SETTLOMETER TEST INFORMATION

DAILY DATA SHEET

DATE________________

DAY________________

SAMPLE IDENTIFICATION__ ______________________

SSR = [1000-SSV30] 2

$SSC = \frac{ATC \times 1000}{SSV}$

Operator:

Time Of Test________

Time	SSV CC/L	SSC %	
			ATC______
0	1000		ATC______
5			RSC______
10			RSC______
15			
20			DOB______
25			
30			DOB______
40			TURB______
50			SSR______
60			
	Time to Float		

Operator:

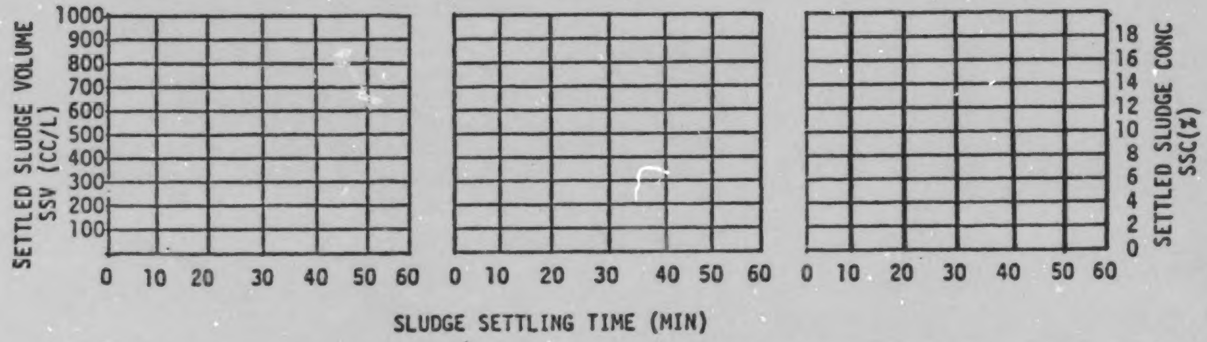
Time Of Test________

Time	SSV CC/L	SSC %	
			ATC______
0	1000		ATC______
5			RSC______
10			RSC______
15			
20			DOB______
25			
30			DOB______
40			TURB______
50			SSR______
60			
	Time to Float		

Operator:

Time Of Test________

Time	SSV CC/L	SSC %	
			ATC______
0	1000		ATC______
5			RSC______
10			RSC______
15			
20			DOB______
25			
30			DOB______
40			TURB______
50			SSR______
60			
	Time to Float		



ADDITIONAL INFORMATION			RETURN SLUDGE INFORMATION						
Time	D.O.	DOB FT.	Time Begin	Time Ended	Total Time-Min	RSF Gal/Min	Total Gal	RSC %	Percent Return
TOTAL									
AVE									

4. RSC: Return Sludge Concentration

The concentration of return sludge, expressed as percent by volume, and measured by the centrifuge.

Assumptions:
1. Calculated SSC for any given time is the same as the RSC for that detention time.
2. Clarifier removes sludge uniformly.
3. A change in return rates changes the return sludge concentration and the sludge detention time in proportion to the sludge settling curve.
4. Sludge detention times less than 30 minutes may not be realistic due to physical weakness in the clarifier and in the clarifier model (settleometer).

The first understanding needed of the sludge quality based control concept is the ability to define some general characteristics of the sludge. Sludge quality was defined in detail in previous lessons but Figure 5 summarizes the settling characteristics needed for return sludge control. The two states, "rapid" and "slow", describe the conditions where return problems can be encountered. Some operators have found that with a large piece of yarn and these profiles drawn on a bulletin board provides a good daily indicator of sludge quality. The careful use of colored pins provides a convenient mechanism for placing data points on the board and the yarn placed over the pins provides a quick and visual comparison of sludge quality.

Figure 6 provides definition of typical ranges for return sludge control. This band of typical RSC data points can also be shown on the sludge quality board which allows for a visual comparison of measured RSC's to typical RSC's. The identification of the typical band has been derived from experience but it has some rational justifications which include the following:

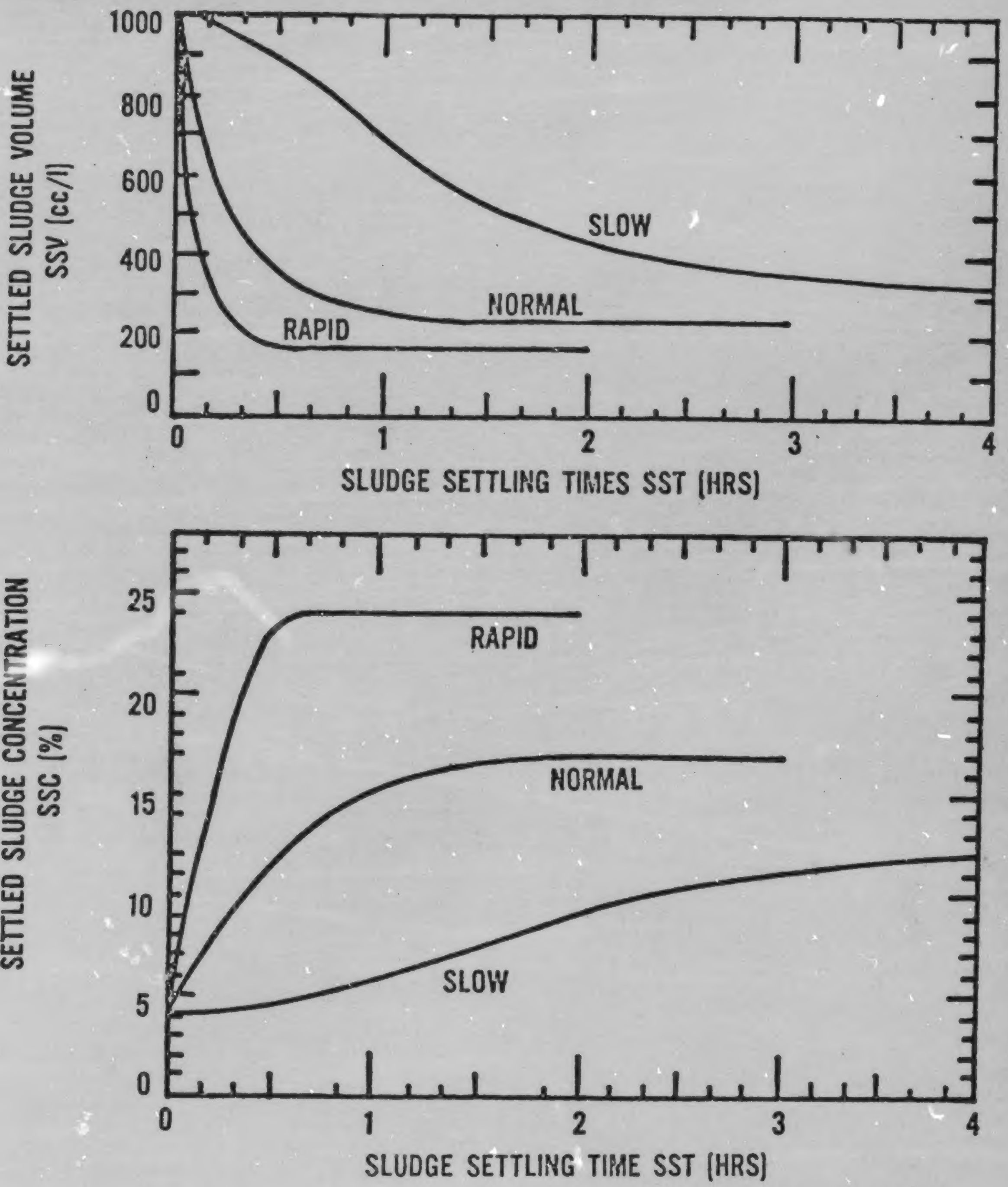


FIGURE 5. .– SSV and SSC CURVES for Slow, Normal and Rapid settling and concentrating activated sludges.

(After West)

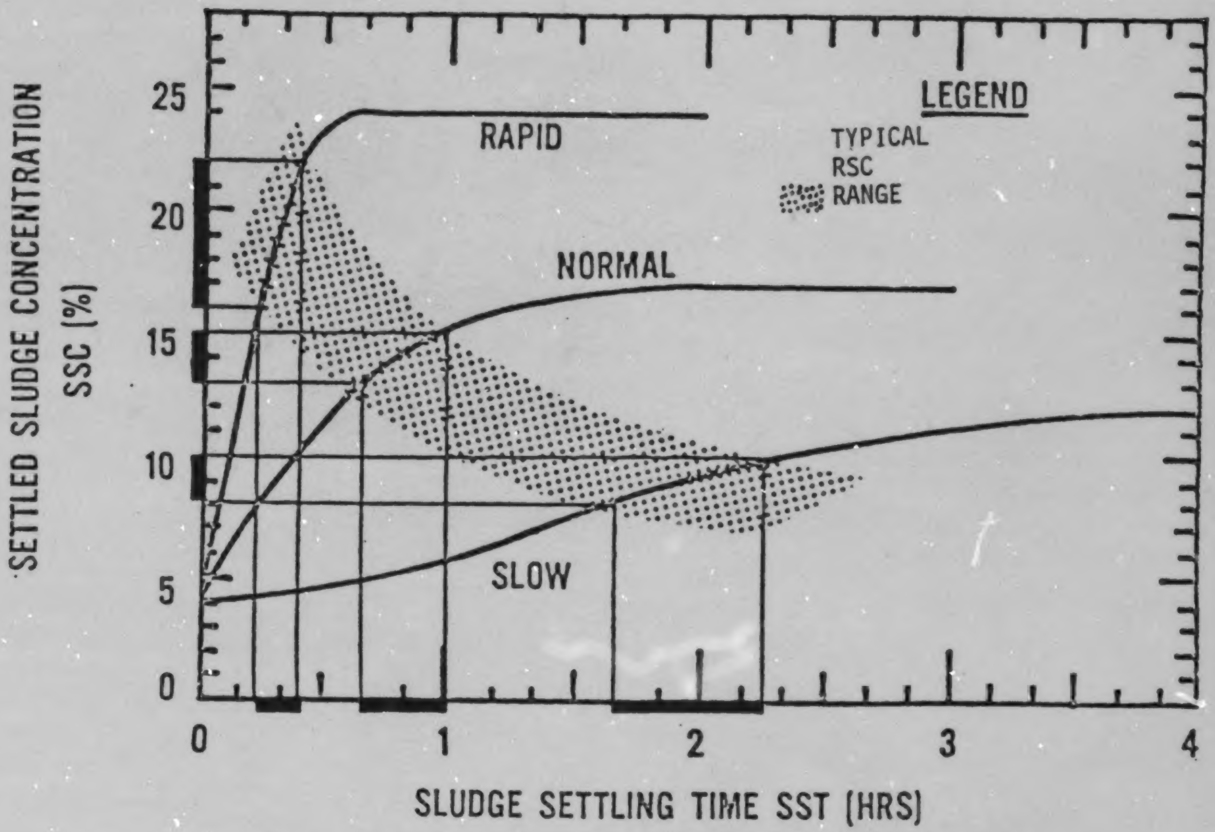


FIGURE 6. SSC RANGE FOR RSC CONTROL

(After West)

Selection of Typical RSC's

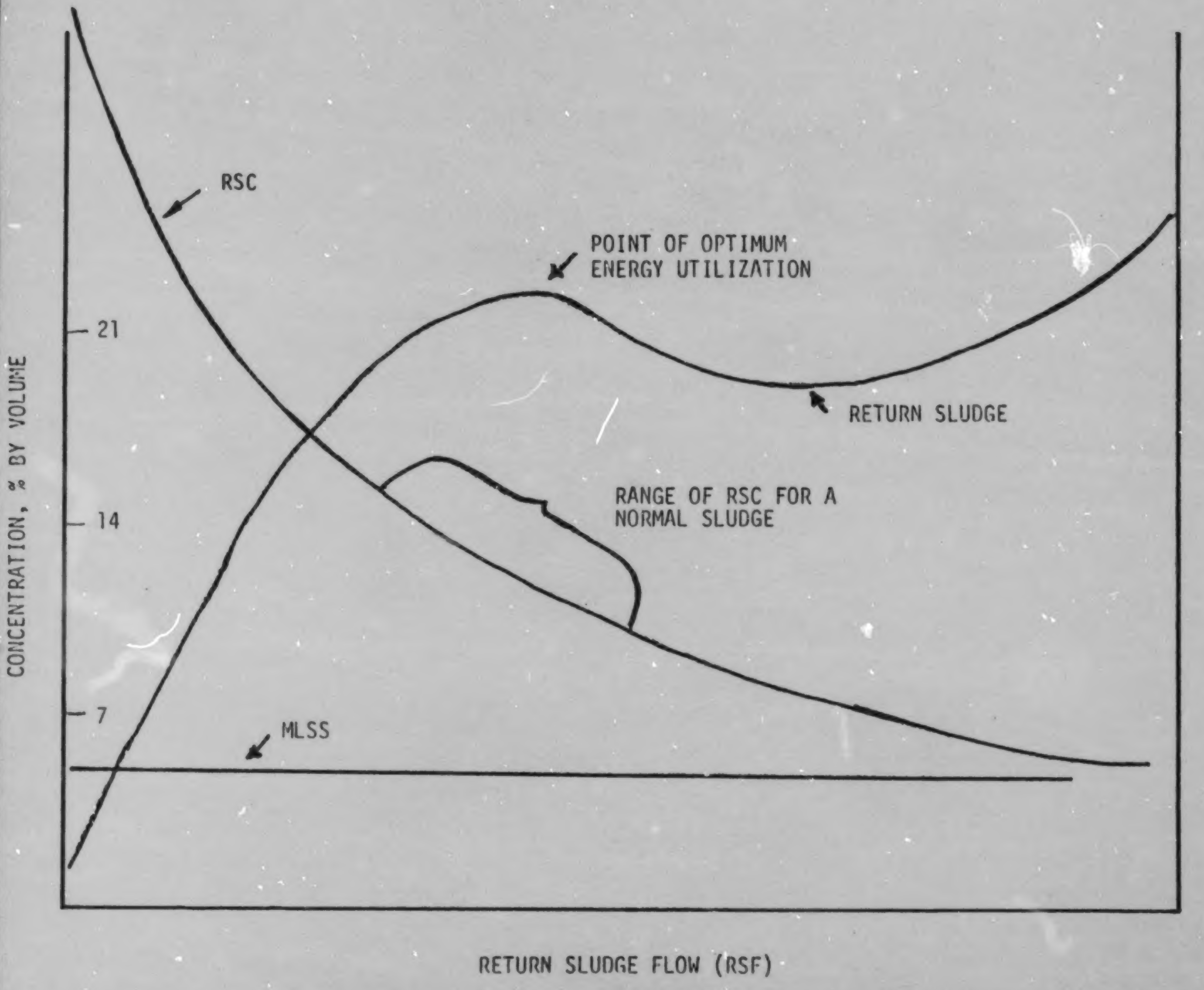
1. Sludge settling times less than ½ hour may result in collection problems in the clarifier and should be avoided.
2. Return concentration on the flat portion of the curves do not provide a controllable range, i.e. a change in RSF will not correspond to a measurable change in RSC.
3. The matching of the RSC to the "knee" of the concentration curve results in an energy efficient control range (Figure 7), if we assume that the return sludge flow changes the return concentration as a function of settling profile.
4. The return sludge set point for slow settling sludges provides maximum thickening capabilities and maximum aeration detention times through the selection of low return rates.

Trend Control

The previous discussions have pointed out numerous assumptions that are built into various return sludge control schemes. In order that these assumptions are not lost in the day-to-day management of process control, the use of a trend analysis is recommended. Figure 8 presents an example of some typical sludge settling data used for managing return sludge control. This figure shows three phases of a return sludge adjustment program. Phases I and II are examples where the sludge quality has changed as demonstrated by the rapid changes in the settling curves. Therefore, changes in the return sludge target were made, i.e. from 14% to 18% for the faster settling sludge. It should be noted that this approach should lead to a steady sludge blanket in the clarifiers which could easily be confirmed and used as a feedback flag on the return sludge control capability. Phase III is a typical condition for a "normal" sludge. Slight

Figure 7.

THE EFFECT OF RETURN SLUDGE REMOVAL AS A FUNCTION OF RETURN FLOW RATE



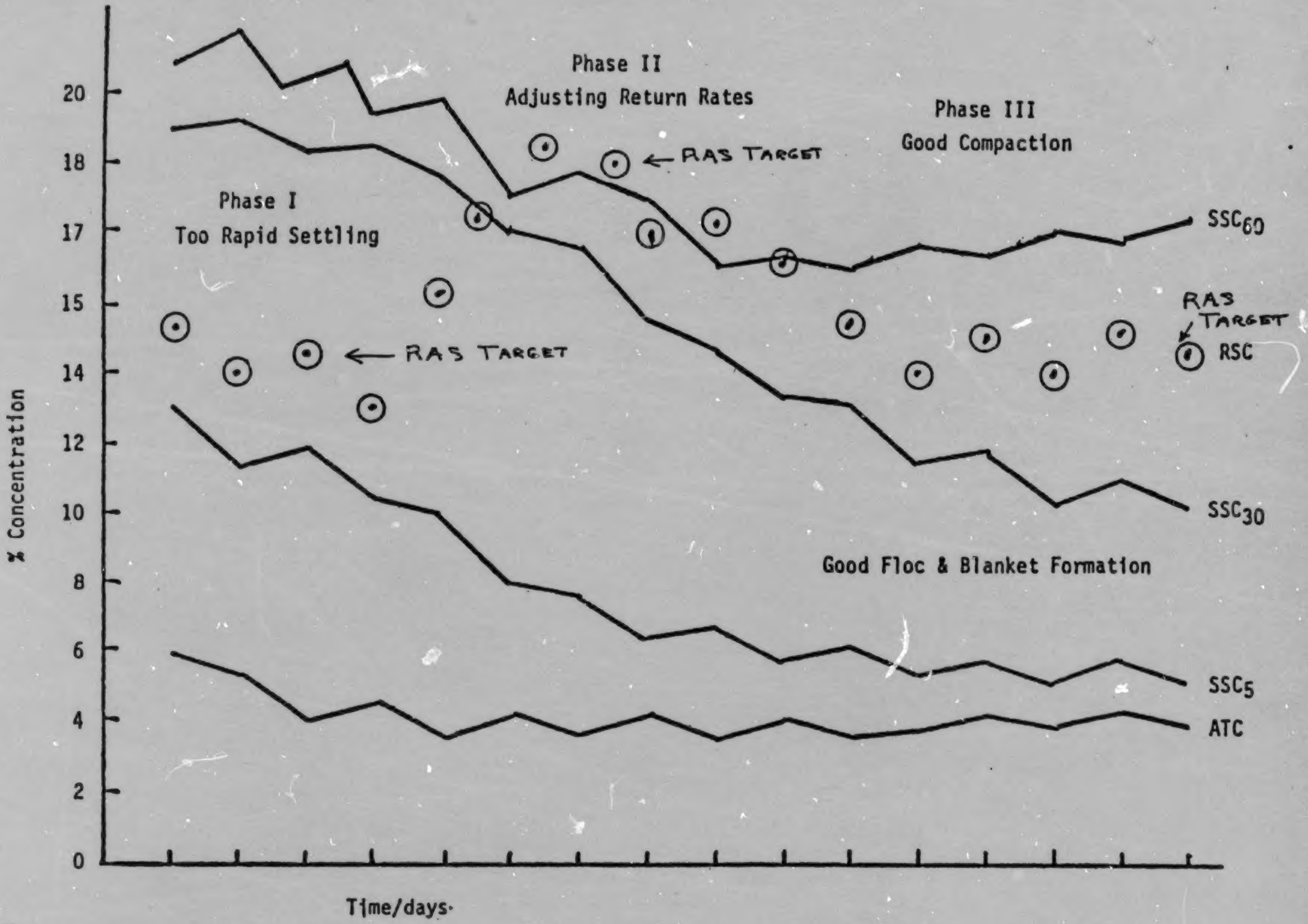


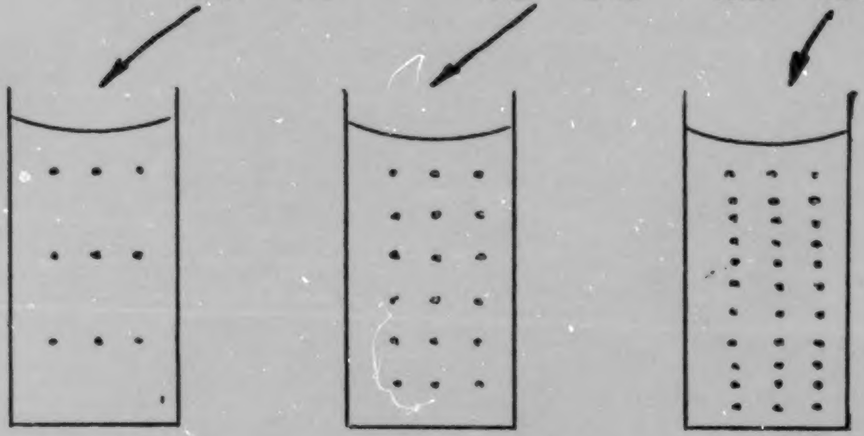
FIGURE 8. SLUDGE SETTLING TREND CHART

deviations from this state will show up if the trend plot is maintained.

Clarifier Efficiency

As we've stressed throughout this section, one major objective of return sludge control is to reduce the loss of unnecessary solids in the effluent. One method to determine the success of this method is through turbidity analysis (Figure 9). The tests are easy to perform and follow the general guidelines of any turbidity test. The task for this analysis is to compare the effluent turbidity to a standard that is representative of the sludge quality but is free of any clarifier influence. The standard that is used in many plants is simply a measurement of effluent turbidity after it has been stationary for one hour. If there is no or little difference in the two numbers, then the clarifier is doing a perfect job. If there is a very large difference such as ten-fold, then the clarifier is doing a very poor job.

FIGURE 9. CLARIFIER EFFICIENCY ANALYSIS


SAMPLE: 1 HR.
THE SETTLED SAMPLE
FINAL CLARIFIER GRABS
TURB. = 1-5
TURB. = 5-15
TURB. = 15-25
ANALYSIS:
GOOD QUALITY BIOMASS
TYPICAL CLARIFIER EFFLUENT
POOR CLARIFIER EFFICIENCY

Lesson 6: Waste Sludge Control

Return activated sludge control was given as the prime objective of removing solids from the final clarifiers. Waste sludge control, on the other hand, is the primary tool for operators to regulate the quantity of solids in the activated sludge system. The system as defined earlier includes both the aeration tanks and the clarifiers. The solids in the system are commonly referred to as the inventory. Remembering that the solids are mainly composed of microorganisms, waste control is used to regulate the system inventory of microorganisms by wasting excess organisms out of the system.

A second goal of waste control is to regulate the sludge quality. As defined earlier, sludge quality is the collective but subjective analysis of the activated sludge. An increase or decrease in system inventory changes the relative oxidation pressures exerted on the system when all other factors are the same and ultimately changes the efficiency of the process.

System Inventory Control

System inventory control means nothing more than being on top of the solids ("bugs") in the plant. Too many times activated sludge control becomes so involved in generating control parameters and monitoring effluent parameters that the original purpose of the control parameter becomes lost. The purpose of solids control can be easily put in the perspective of a farmer. The activated sludge system is a farm and the crop is activated sludge. Careful attention is given by a farmer to monitor the yield of the crop. The crop yield tells the farmer how effective his irrigation was, how effective his nutrient feed program was and how effective his land management control was. The operator of a waste treatment plant likewise also has a crop yield and he needs to monitor the yield in order to assess the impacts of his aeration system, to assess the impacts of plant loadings and to assess his general "bug" management control.

The good operator looks closely at his plant (farm) in order to obtain a more timely response from various parameters. Like the farmers, the actual yield is only determined after the crop is harvested and is dependent on a variety of circumstances. He monitors the dissolved oxygen levels, he monitors his substrate loading conditions, he monitors the "quality" of the sludge settling characteristics, and he monitors the balance of his "bugs" to achieve the best environment he can provide so that the microorganisms can efficiently break down the organic material in the sewage.

Material Balance:

The first step in being a good operator (farmer) is in knowing where the "bugs" (workers) are. A material balance program should be established which provides enough information to enable a person to evaluate the "bugs". A material (bug) balance program should be able to answer the following questions:

1) How many "bugs" are in every unit process?
2) How many "bugs" are coming and going from the various units?
3) How long do the "bugs" stay in any one unit?

The data obtained to answer these questions should be updated frequently enough to ensure that major variations do not occur.

Considerable amount of information can be obtained from a material balance evaluation. In most cases, the full utilization of a material balance is limited by a lack of flow data. However, through appropriate use of solids sampling programs and careful consideration of pumping capacities or flow measurement capabilities, many of the limitations can be reduced.

The following detailed example of a clarifier demonstrates the type of data that can be derived from a simple material balance approach.

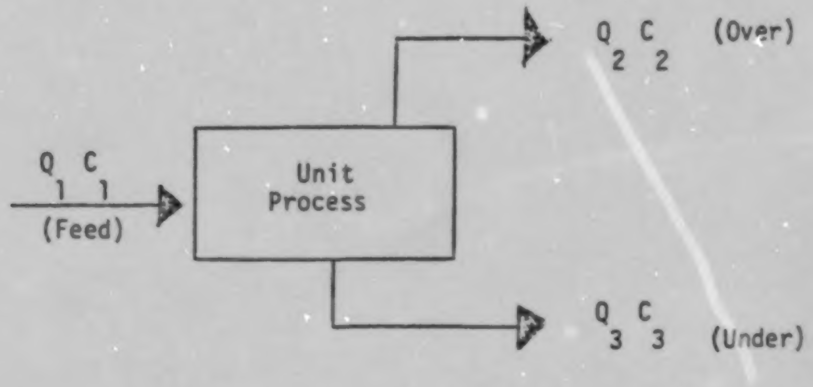
EXAMPLE: "CALCULATING FLOWS & EFFICIENCIES FOR A CLARIFIER

Given: Any process unit, such as thickener or clarifier, where only one (1) flow is known.

Data Needed: Measure concentrations of solids on all flows entering or leaving process. Concentrations can be TS, TSS, or centrifuge, but don't mix.

Assumption: Solids are not destroyed or biologically grown, such as in a digester or aeration tank. There are no additional sources of either liquid or sludge to the tank such as cooling water.

Rationale:



Where Q = Flow

C = Concentration

Flow Equation:

(1) $$Q_1 = Q_2 + Q_3$$ If two (2) flows known

(2) $$Q_2 = Q_1 \left[\frac{C_1 - C_3}{C_2 - C_3} \right]$$ If feed flow is known

(3) $$Q_3 = Q_1 \left[\frac{C_1 - C_2}{C_3 - C_2} \right]$$ If feed flow is known

(4) $$Q_1 = Q_3 \left[\frac{C_3 - C_2}{C_1 - C_2} \right]$$ If under flow is known

(5) $$Q_1 = Q_2 \left[\frac{C_2 - C_3}{C_1 - C_3} \right]$$ If over flow is known

Efficiency Equations:

(1) If flows are known $$\% \text{ Removal} = \left[\frac{Q_1 \times C_1 - Q_2 \times C_2}{Q_1 \times C_1} \right] \times 100$$

(2) If flows are not known $$\% \text{ Removal} = \left[1 - \frac{C_2}{C_1} \times \left[\frac{C_1 - C_3}{C_2 - C_3} \right] \right] \times 100$$

NOTE: $$\text{Efficiency} = \frac{\text{lbs in} - \text{lbs out}}{\text{lbs in}} \times 100$$

CLARIFIER DATA:

Given:	Feed	Over	Under
	$Q_1 = 10$ gpm	$Q_2 = ?$	$Q_3 = ?$
	$C_1 = 3000$ mg/l	$C_2 = 500$ mg/l	$C_3 = 10{,}000$ mg/l

Find Flow:

Flow Over = $Q_2 = Q_1 \left[\dfrac{C_1 - C_3}{C_2 - C_3} \right] = 10 \text{ gpm} \left[\dfrac{3000 - 10000}{500 - 10000} \right]$
eg (2)

$$Q_2 = 10 \text{ gpm} \left[\frac{-7000}{-9500} \right] = 7.4 \text{ gpm}$$

Flow Under = $Q_3 = Q_1 \left[\dfrac{C_1 - C_2}{C_3 - C_2} \right] = 10 \text{ gpm} \left[\dfrac{3000 - 500}{10000 - 500} \right]$
eg (3)

$$Q_3 = 10 \text{ gpm} \left[\frac{2500}{9500} \right] = 2.6$$

Check: $Q_1 = Q_2 + Q_3$
Fg (1)

$$Q_1 = 7.4 + 2.6 = \underline{\underline{10 \text{ gpm}}}$$

Find Efficiency:

Eg (1)

$$\% = \left[\frac{Q_1 \times C_1 - Q_2 \times C_2}{Q_1 \times C_1}\right] \times 100 =$$

$$= \left[\frac{10 \text{ gpm} \times 3000 \text{ mg/l} - 7.4 \text{ gpm} \times 500}{10 \text{ gpm} \times 3000 \text{ mg/l}}\right] 100$$

$$= \underline{\underline{87.7\%}}$$

Eg (2)

$$\% = 1 \left[\frac{C_2}{C_1} \times \left[\frac{C_1 - C_3}{C_2 - C_3}\right]\right] \times 100$$

$$= 1 - \frac{500 \text{ mg/l}}{3000 \text{ mg/l}} \times \left[\frac{3000 \text{ mg/l} - 10000 \text{ mg/l}}{500 \text{ mg/l} - 10000 \text{ mg/l}}\right] \times 100$$

$$= \underline{\underline{87.7\%}}$$

Inventory Control

The second significant step of the farmer (operator) is to waste the excess solids from the farm (plant). This problem translates into a determination of excess. Unfortunately, excess solids are not that easy to determine because an activated sludge plant provides many places to hide or to distort the measurement of solids. Clarifiers are excellent places to hide "bugs". Changes in flow pattern throughout the day distorts most sampling programs. Growth of the "bugs" changes as the specific populations of organism change, which further distorts analysis. Because of these problems, various methods or control parameters have been devised to evaluate the excess sludge or the "bug" growth. Several of these are listed below.

Methods used to evaluate excess sludge:

1. Settleometer Data
2. Sludge Age
3. F/M
4. MCRT or CRT or SRT
5. MLSS Trends
6. ASU - Aeration Sludge Units
7. CSU - Clarifier Sludge Units
8. Lbs. Primary Eff. SS
9. Sludge Quality

Before the specific control parameters are discussed, however, it is important to further define yield and growth.

Yield (Y)

Yield is a term used to describe the quantity of activated sludge produced per pound of BOD_5 introduced to the system per day. As discussed earlier, each of the four major variations of the activated sludge process has a relatively unique yield. Any change in yield for a given BOD_5 load would obviously impact the solids handling characteristics of the treatment plant.

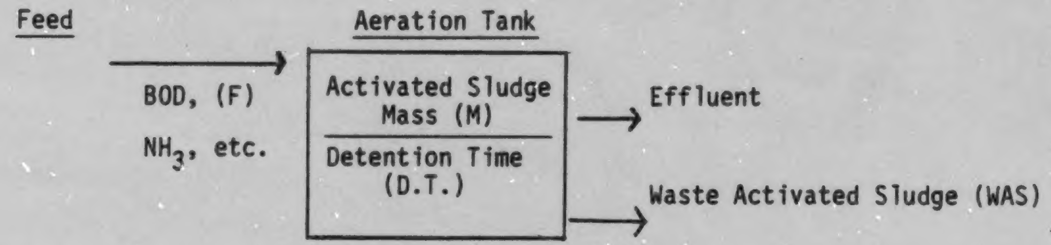
Growth:

If we assume that pounds of activated sludge measures the quantity of microorganisms, then the lbs/day is the net growth rate of the microorganisms.

The growth rate or the production of microorganisms in an activated sludge plant is influenced by many factors. The most commonly recognized factor is the type of feed (measured by BOD) loaded to an activated sludge system. Yet the growth rate is influenced by many other conditions. The lack or excess of some of these factors may override the BOD considerations. Some of these factors are summarized by the following expression:

$$\text{Growth} = \text{Function } [\text{BOD}, O_2, \text{Temp}, \text{Time}, \text{Mixing}, \text{MLSS}, \text{pH}, NH_3, PO_4^{-3}, Fe^{+3}\ \text{R.R.}]$$

Many attempts, by both scientists and operators, have been made to find exact relationships which predict the growth of microorganisms. Sometimes this can be done for a specific plant with a specific set of conditions, but it is important to realize that if the conditions change, then a new relationship may be needed. For this reason it is imperative to try to understand the factors and their limitation which affect process control. More discussion will be provided on this later, but for now a simple block diagram of an activated sludge plant better demonstrates the relationship of various key parameters.



If F represents the food to the system and M represents the mass of microorganism, lbs. WAS is equal to the growth, then the following are process control relationships which can be derived from the above diagram:

1. $\frac{\text{Mass}}{\text{Lbs. WAS}} : \frac{\text{lbs. Mass}}{\text{lbs. Growth}}$ (also referred to as MCRT, SRT or CRT)

2. Food/Mass : $\frac{\text{lbs. Food}}{\text{lbs. Mass}}$ (F/M)

3. WAS/BOD or yield: : $\frac{\text{lbs. Growth}}{\text{lb. Food}}$ (Y_o)

A mathematical relationship that can also be produced from the above relationships follows:

$$\frac{1}{\text{MCRT}} = Y_o \times F/M = \text{Solids growth/lbs. system solids}$$

When MCRT $= \frac{\text{System Solids}}{\text{System Waste}}$

F/M = lbs. BOD/lbs. System Solids

Y_o = lbs. Solids growth/lbs. BOD Fed

This equation is dependent on how each term is defined, but when used properly it is an excellent relationship to focus operator's perspective on the process control parameters that may be used.

Specific Control Parameters:

Each process control parameter can be supported by case studies to show its merits. Kinetic analyses can be used to justify the authenticity of their derivations. However, the most important concerns are the restrictions on any individual plant to obtain representative information for making process control decisions. Two of the most commonly used control parameters are discussed further in this section. Remember, however, that the only real test of any control parameter is its ability to track changes in the system to provide for an appropriate sludge yield and to control inventory numbers that produce a good "sludge quality". The actual value ultimately chosen to waste then comes from a combination of all other available inputs as described in the lesson on sludge quality.

When using MCRT and F/M values as discussed above, the following conditions must be true:

1) an accurate measurement of the system solids (including aeration tanks and clarifiers) must be used;

2) the solids measured are a representative measurement of the "active biomass", MLVSS;

3) measurements of WAS and secondary effluent suspended solids must represent the loss of "active biomass" from the system;

4) measurements of influent and effluent food (BOD, TOC or COD) must represent the food available and the food utilized by the "active biomass";

5) there must be no limitations to growth other than available food, i.e., detention time, D.O., nutrients, temperature, and mixing must be sufficient and toxic materials must be absent;

6) growth of the "active biomass" in the system must be linear to the amount of food provided;

7) the system must operate at a "steady state", i.e., the ratio of food provided to the amount of "active biomass" must remain constant.

MCRT:

When MCRT is used as a control option, it must meet the tests for authenticity as described above.

Values for MCRT can be calculated by several methods. The major differences occur in the calculation of total system solids. At some plants, SRT or CRT which are similar to MCRT, are calculated by using total pounds of solids under aeration only. Clarifier solids may be neglected if it can be shown that these solids do not represent a significant fraction of the aeration solids and that there are no major changes in the quantity from time to time (i.e., sludge blankets or return sludge concentrations do not have significant variations). Volatile solids are generally used if any significant changes in volatility are expected, but in many circumstances a TSS value can be adequately used if the volatile solids fraction is periodically checked.

There are many ways that clarifier solids can be calculated. Before any specific method is used, its validity should be checked in a plant specific environment. One method that is fairly independent of any plant specific conditions is to directly measure the average clarifier suspended solids. A "sludge judge" (clear plastic tube with a foot valve on one end) can be used to collect a core sample from the clarifier. A TSS value determined from this sample and the clarifier volume is the only information needed. An example of typical data that must be collected before starting the calculations is as follows:

Item	Value
Average MLSS for the day	3117 mg/l
Volatile solids in MLSS	68%
Number of aeration tanks in service	2
Aeration tank volume	2.75 MGD
Flow	34.4 MGD
WAS flow	0.4 MGD
Secondary effluent SS	8 mg/l
WAS suspended solids	10375 mg/l
WAS volatile solids	69.2%
Clar TSS	735 mg/l
Number of clarifiers in service	2
Clar Vol.	2.5 MGD

Calculation procedure:

1. Aerator VSS, mg/l

= Average MLSS X Volatile Solids Content

= 3117 mg/l X 0.68

= 2120 mg/l

2. Aerator VSS, K-lbs

$$= \frac{\text{Aerator VSS, mg/l} \times \text{no. of tanks in service} \times 2.75 \times 8.34}{100}$$

$$= \frac{2120 \text{ mg/l} \times 2 \text{ tanks} \times 2.75 \text{ MG/tank} \times 8.34 \text{ lb/gal}}{100}$$

= 97.2 K-lbs

3. Clarifier VSS, K-lbs

$$= \frac{\text{Clar TSS X no. tanks X 2.5 X 8.34 X 0.68}}{1000}$$

$$= \frac{735 \text{ X } 2 \text{ X } 2.5 \text{ X } 8.34 \text{ X } 0.68}{1000}$$

= 20 K-lbs

4. Total system solids

= Aerator VSS + Clar VSS

= 97.2 K-lbs + 20 K-lbs

= 117.2 K-lbs

5. Effluent VSS, mg/l

$$= \text{Effluent SS, mg/l X } \frac{\text{Volatile Solids in MLSS}}{100}$$

= 8 mg/l X 0.68

= 5.4 mg/l

6. Effluent VSS, K-lbs/day

$$= \frac{\text{Eff. VSS, mg/l X (Flow - WAS Flow) X 8.34}}{1000}$$

$$= \frac{\text{5.4 mg/l X (34.4 - 0.4) MGD X 8.34 lb/gal}}{1000}$$

= 1.5 K-lbs/day

7. WAS VSS, K-lbs/day

$$= \frac{\text{WAS SS, mg/l X WAS VS, \% X WAS Flow, MGD X 8.34 lb/gal}}{100 \text{ X } 1000}$$

$$= \frac{\text{10375 mg/l X 69.2\% X 0.4 MGD X 8.34 lb/gal}}{100 \text{ X } 1000}$$

= 23.9 K-lbs/day

8. Total Volatile Solids Wasted, K-lbs/day

= Eff. VSS, K-lbs/day + WAS VSS, K-lbs/day = 1.5 + 23.9

= 25.4 K-lbs/day

9. MCRT, days

$$= \frac{\text{Total System VSS, K-lbs}}{\text{Total Volatile Solids Wasted, K-lbs/day}}$$

$$= \frac{\text{117.2 K-lbs}}{\text{25.4 K-lbs/day}}$$

= 4.6 day

F/M:

When F/M is used as a control option, it must also meet the conditions described previously.

When calculating values for F/M, the laboratory results for BOD, TOC, or COD may be used for determining F. At some plants TOC or COD results combined with a BOD/TOC ratio are used to calculate an estimated F/M ratio which is used in determining wasting rates. Then an actual F/M ratio is calculated when the BOD_5 values are available.

Item	Value
MLSS	3117 mg/l
Volatile suspended solids in MLSS	68%
Number of aeration tanks in service	2
Aeration tank volume, M gal	2.75
TOC of settled sewage	99 mg/l
BOD of settled sewage	175 mg/l
BOD/TOC ratio	1.5
Settled sewage volume	34.4 MG

Calculation procedure for F/M:

1. Estimated BOD in settled sewage, mg/l

   = TOC of settled sewage, mg/l X $\frac{\text{BOD}}{\text{TOC}}$ ratio

   = 99 mg/l X 1.5

   = 148 mg/l

2. Estimated total BOD, K-lbs, or Food (F) to the aerators

   = Estimated BOD, mg/l X settled sewage volume, MGD X 8.34 lbs/gal ÷ 1000

   = 148 mg/l X 34.4 MG X 8.34 ÷ 1000

   = 42.5 K-lbs

3. Aerator volume, MG

   = Number of aerators in use X 2.75 MG/tank

   = 2 tanks X 2.75 MG/tank

   = 5.5 MG

4. Mixed liquor volatile suspended solids (MLVSS), mg/l

   = MLSS (average for that day), mg/l X volatile suspended solids, % ÷ 100

   = 3117 mg/l X 68% ÷ 100

   = 2120 mg/l

5. Total volatile solids in the aerator, K-lbs or microorganisms (M) in the aerators

   = MLVSS, mg/l X aerator volume, MG X 8.34 lbs/gal ÷ 1000

   = 2120 mg/l X 5.5 MG X 8.34 lbs/gal ÷ 1000

   = 97.2 K-lbs

6. F/M, daily estimated value

   = Estimated total BOD, K-lbs ÷ total volatile solids in aerator, K-lbs

   = 42.5 K-lbs ÷ 97.2 K-lbs

   = 0.44

MLSS (MLVSS):

Constant mixed liquor suspended solids is another common control parameter. In this case, MLSS values are used to represent the system inventory. Again, the same considerations of validity for MCRT and F/M still apply.

One major advantage of the constant MLSS approach is that it simplifies the calculation procedures. On the other hand, it puts a greater burden on the staff to ensure that variations in loading or clarifier inventories are not misrepresenting the data. A common problem would be for an operator to decrease his waste because the MLSS values were dropping, when in actuality the aeration inventory was stacking up in the final clarifiers.

Sludge Quality (Oxidation Pressure):

Sludge quality has been discussed in depth in a past lesson and is also a significant factor in waste control. Unfortunately, there is no precise calculation of sludge quality, but as discussed earlier, we can speak of high oxidation pressures and low oxidation pressures. Any changes, up or down, in the oxidation pressure could be interpreted just as if the F/M or MLSS values went up or down and, consequently, a new waste target should be derived.

WAS Adjustments:

The actual decision to change the waste when any single or combination of control parameters is used is not necessarily an easy one. Two general procedures of calculation and trend control can be used for determining wasting rates.

First, a fixed relationship can be developed from the control parameters to calculate a sludge yield. The yield calculation then represents the target for wasting, and from the target a waste flow can be calculated. This procedure has the advantage of reducing all the steps down to a "fixed" procedure that could be put on a nomengraph or a computer. This procedure would also reduce the chance of multiple decision makers from shift to shift who might be making waste decisions that contradict each other. On the other hand, this approach implies a high degree of precision on the final decision when, in fact, there were numerous assumptions buried in the calculations. Often these assumptions are not entirely correct and can lead to erroneous results.

A second approach, therefore, is to compare wasting to the selected control parameter(s) and monitor the trends. Table 1 represents an overview of this approach. The last column, "Response", provides for a targeted change in direction of the waste program. When the "Response" calls for a decrease in WAS then the waste should be reduced by approximately 10%. The next day this cycle should be repeated and a new analysis made. If the wasting decision was too aggressive, the next analysis should reveal a deviation from target in the other direction which should result in an increase of waste by 10%. Note that 10% was given as the increment of change. This is a standard that is recommended for "typical" plants. Experience and plant specific conditions could dictate a much different response. Those responses, however, would impose a higher degree of risk and their rationale are beyond the scope of this work.

Refer to Figure 1 to review how wasting would affect oxidation pressure through its impact on the control parameters discussed above. Generally, increased wasting will shift the balance toward under-oxidized (young) sludge and decreased wasting will shift the balance toward over-oxidized (old) sludge.

Visual observations of the aeration basin and clarifier and observations of the settleometer also provide hints as to the proper wasting response. In addition, microscopic examination of sludge will add to the data bank. These observations used in conjunction with trend charts will help the wasting picture come into focus.

The solids inventory procedures developed by West utilize data generated in the centrifuge and settleometer tests to help establish wasting schedules. This section presents thoughts on sludge wasting based on these concepts.

This section describes an orderly procedure to control sludge wasting by day-to-day evaluation of the trend charts. In other words, the operator can usually use the basic control test data to determine whether to hold,

OXIDATION PRESSURE FORCES

FORCES	FORCES
HIGH F/M	LOW F/M
LOW MCRT, CRT, SLUDGE AGE	HIGH MCRT, CRT
LOW D.O.	HIGH D.O.
LOW MLSS	HIGH MLSS

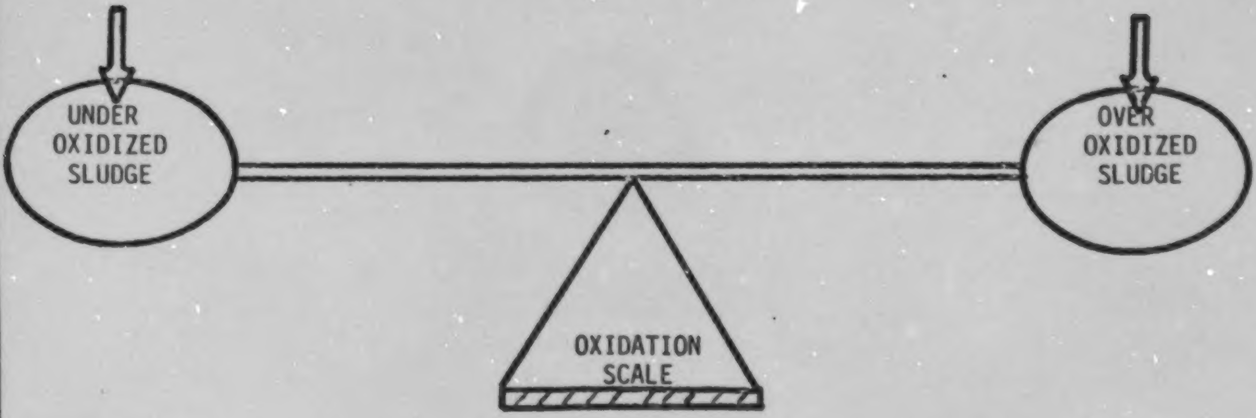

UNDER OXIDIZED SLUDGE
OVER OXIDIZED SLUDGE
OXIDATION SCALE

FIGURE 1

TABLE 1.

STANDARD OPERATING PROCEDURES FOR WAS CONTROL

METHOD OF CONTROL	WHAT TO CHECK	WHEN TO CHECK	CALCULATIONS	FREQUENCY OF ADJUSTMENT	CONDITIONS	PROBABLE CAUSE	RESPONSE
CONSTANT F/M	MLVSS & INFLUENT COD	DAILY	F/M BASED ON - $\frac{\text{5 DAY AVG.}}{\text{5 DAY AVG. MLVSS}}$	DAILY	ACTUAL F/M: HIGH SATISFACTORY LOW	EXCESSIVE WASTING INSUFFICIENT WASTING	REDUCE WAS INCREASE WAS
CONSTANT MLVSS	MLVSS & INFLUENT COD OR BOD	DAILY	VOLATILE SOLIDS INVENTORY	DAILY	ACTUAL MLVSS: HIGH SATISFACTORY LOW	INSUFFICIENT WASTING EXCESSIVE WASTING	INCREASE WAS REDUCE WAS
CONSTANT MCRT	MLSS WAS_{SS}, Q_{WAS}, & $EFFL_{SS}$	DAILY	5 DAY AVERAGE SOLIDS INVENTORY 5 DAY AVERAGE OF SOLIDS IN WAS 5 DAY AVERAGE OF SOLIDS IN EFFLUENT	DAILY	ACTUAL MCRT: HIGH SATISFACTORY LOW	INSUFFICIENT WASTING EXCESSIVE WASTING	INCREASE WAS REDUCE WAS
OXIDATION PRESSURE	SETTLE-OMETER TURBID. MICRO.	DAILY	SVI SSV SSC FILAMENTS PROTOZOA	DAILY	OVER OXID. SATISFACTORY UNDER OXID.	INSUFFICIENT WASTING EXCESSIVE WASTING	INCREASE WAS REDUCE WAS

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for Aerobic Biological Wastewater
Treatment Facilities

increase or decrease wasting. The direction and the rate at which the sludge quality (SSC) and sludge age have responded to previous wasting (XSU) adjustments will be revealed by the SSC and XSU trend charts. The progressive trend chart relationships will then indicate when the corrective wasting schedule should be readjusted.

> Proper wasting control depends upon satisfying the true process requirements that vary with loading changes and are altered by control adjustments.

> Properly coordinated wasting control is seldom achieved by attempting to establish independent preconceived levels of mixed liquor concentration, F/M, or sludge age.

Normal Settling Sludge:

Continue the established wasting rate if the sludge is concentrating to the desirable 14 to 16 SSC range, the blankets are deep down in the final clarifier and the final effluent is clear and solids free. The end results have proven that the true process requirements have been satisfied for the prevailing circumstances.

Wasting schedules should be adjusted to meet the new demands when the trend chart comparisons show that sludge quality and process balance are starting to shift away from optimum.

Rapid Settling Old Sludge:

Sludge that concentrates too rapidly (i.e., SSC exceeds 20 percent in less than 1 hour) can most always be slowed down to a lower and more desirable SSC range by increasing the sludge wasting rate to reduce sludge age. But the wasting rate should be increased gradually (about 15 percent per day) to progressively replace the older sludge with younger, slower settling sludge.

Two precautions are necessary. If too much sludge is wasted at any one time, the sludge settling rate will usually increase rather than decrease. In such cases, the mixed liquor concentration is reduced immediately without inducing a comparable reduction in sludge age, and the thin sludge will settle faster than a thicker sludge of equal quality. Secondly, the sludge may become extremely slow settling and bulky if the wasting rate is increased too much for too long. This will usually occur when the newly developed slow settling young sludge forms too great a proportion of the total sludge mass.

Sludge wasting rates should no longer be increased, and most probably should be reduced slightly, when the SSC trend line starts falling at an accelerated rate.

The "ashing" and "clumping" in the final clarifier and dark scummy foam on the aeration tanks, associated with old sludge, are practically always eliminated when proper sludge quality is restored.

Slow Settling Sludge:

Sludge Concentration Control

The settling rates of equal quality activated sludges (similar SSCs) vary according to changes in mixed liquor concentrations (ATCs). Thin, low ATC sludges (of equal quality - SSC) settle faster than thicker, high ATC sludges.

At times the activated sludge system can become glutted with excessive sludge solids at excessively high mixed liquor concentrations before the sludge age increases to the point where settling rates are normally increased. Excessive mixed liquor concentration can be reduced, settling rates can be increased and the clarifier sludge blankets lowered, in such cases, by increasing the sludge wasting rate sharply (maybe doubling or tripling the previously established rate) for short time periods until the clarifier sludge blanket retreats to safe levels.

Such "blast" wasting should be discontinued as soon as possible to avoid wasting all the way over to the sludge bulking stage.

Sludge Quality Control

The settling rates of equal concentration (ATCs) activated sludges vary according to changes in mixed liquor sludge quality (SSCs). Young, low SSC, sludges (at equal ATC) settle slower than old, high SSC, sludges.

On a long-term basis, and if the plant is not consistently overleaded, bulking can usually be eliminated by reducing the established wasting rate to increase sludge age.

But this maneuver becomes difficult at times. If wasting is reduced too sharply, or discontinued altogether, the newly developed (slow settling) young sludge proportion of the entire sludge mass may start to increase more rapidly than the old sludge portion. This would reduce, rather than increase, both sludge age and sludge settling rates initially.

Multiple dilution settleometer tests will indicate whether or not an initial short spurt of "blast" wasting is called for before the long-term reduced wasting program is initiated. Multiple dilution tests should be run simultaneously on three portions of the mixed liquor sample. One settleometer should contain 100 percent mixed liquor, the second one about 75 percent mixed liquor and 25 percent final effluent and the third one should contain about 50 percent mixed liquor and 50 percent final effluent.

An initial temporary spurt of "blast" wasting will be appropriate if the diluted sludges settle faster and concentrates to SSC values equal to or greater than the SSC of the undiluted sample. Blasting would be discontinued and sludge wasting should be reduced as soon as the sludge blanket recedes below the clarifier surface water level. Wasting can then be reduced (to increase SSC and improve sludge quality) when the sludge blanket remains safely at lower levels.

Clarifier sludge flow control adjustments must obviously be coordinated with the wasting adjustments. Changes in sludge quality induced by the wasting program will be revealed by the changes in the settled sludge concentration curves which in turn are used to calculate the current clarifier sludge flow percent demand.

As indicated in the above discussion, blast or slug wasting is usually not appropriate. Normally any change in wasting schedule should be made slowly. A change of 10% per day is recommended under normal circumstances. Finally, the importance of creating and using trend charts of the control parameters can not be over-emphasized. It is only through the use of trend charts that the true "steady-state" response of the system can be followed.

Summary

Waste control for the activated sludge process has two goals. First, excess accumulations of biomass must be removed from the system and secondly, the appropriate sludge quality must be maintained to provide efficient treatment.

Excess sludge is a product of bacterial growth in response to organic (BOD) wastes. Many factors affect the net production of wastes and often these factors change or at least change seasonally.

Sludge quality, as defined, is a measurement of the ability of activated sludge to effectively and efficiently remove organics and colloidal material from sewage. Waste control is the most powerful tool the operator has to control sludge quality and, therefore, performance.

Many mathematical relationships have been proposed for wasting, but in practice the operator generally sets waste targets based on observations of many parameters. In this context the trend plot that compare effluent quality to various control parameters or to just pounds wasted is the most general tool to use on any activated sludge plant.

ACTIVATED SLUDGE

Lesson 7: Trend Charts and Testing

Trend Charts

Trend charts are graphs of various plant data and control parameters plotted for each day. They are used because they give a visual representation of changes and fluctuations and, more importantly, of the "trends" that are occurring in data changes. Figure 1 shows a typical trend chart.

Many times moving averages are plotted on trend charts. Moving averages over the past 3, 7, 10 and even 28 days are frequently used. A 3 day moving average, for example, is a plot of the average of the values for the last three days. A moving average plot tends to smooth out the data, de-emphasizing the highs and lows. The longer the averaging period the smoother the curve and the less impact highs and lows will have. Moving averages are used with trend chart plots of operational control parameters because it is a more accurate representation of the actual "trend" of the system. Short term fluctuations or one time sampling and testing errors will not confuse the visualization of the true trend.

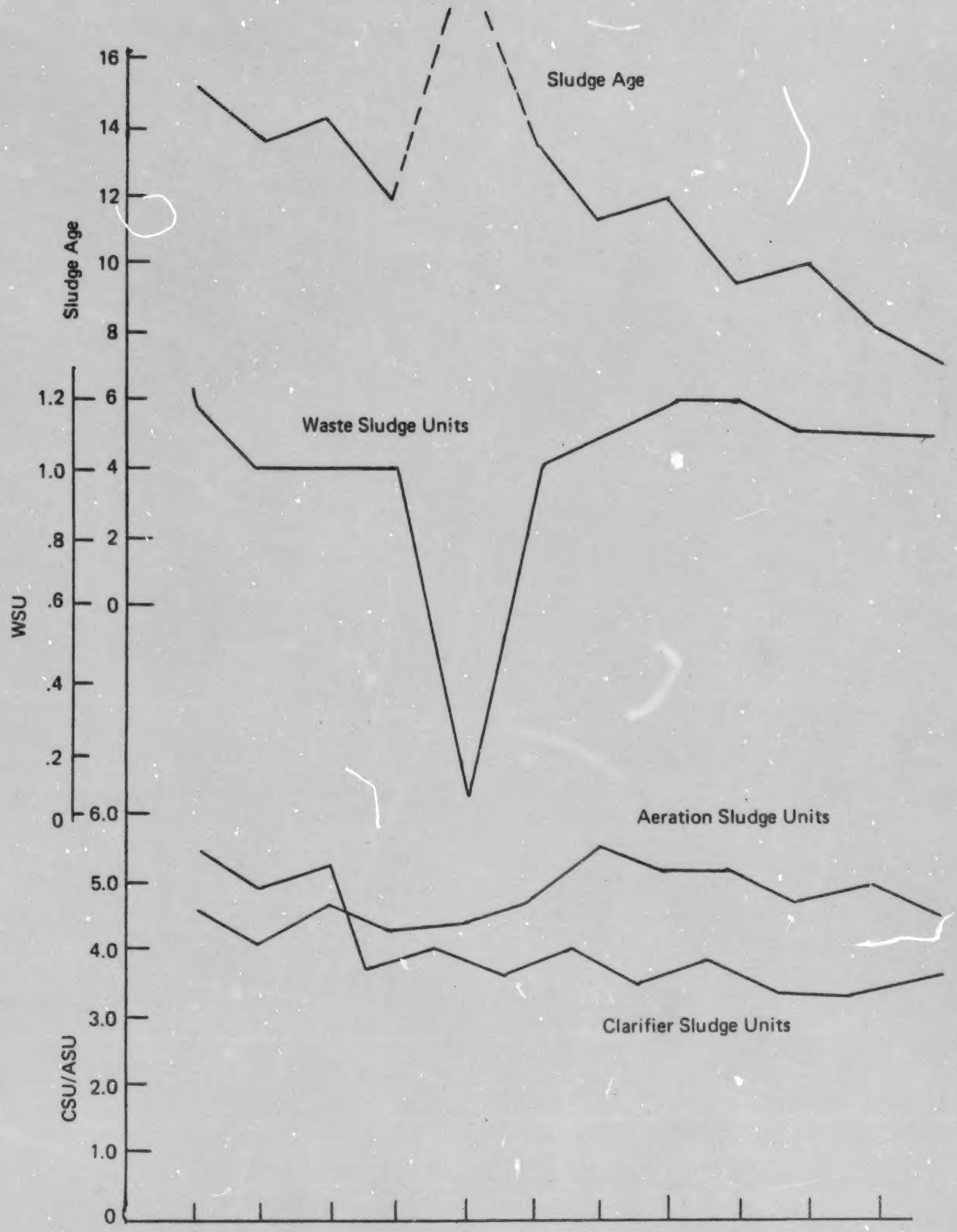
Figure 2 shows an example of the calculation of a 5 day moving average of plant operational control data.

Testing

The most common operational control tests used in the control of the activated sludge test are the Settleometer, Centrifuge, Depth of Blanket, and Oxygen Uptake Tests. In addition, operators may find determination of oxygen profile, turbidity and calculating sludge mass balance (sludge

Figure III

SOLIDS BALANCE TRENDS



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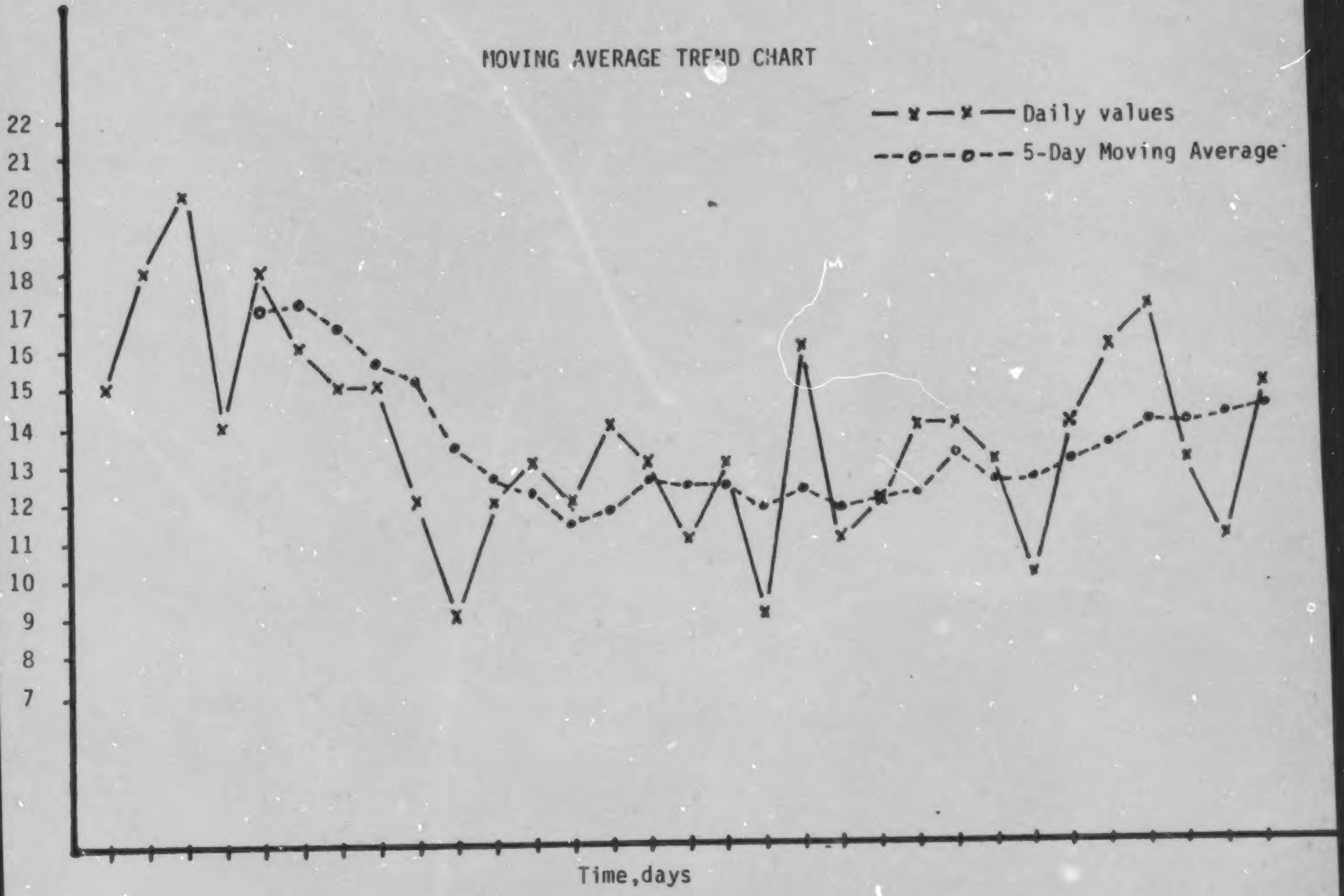
MOVING AVERAGE TREND CHART
—x—x— Daily values
--o--o-- 5-Day Moving Average
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
Time,days

inventory) useful. These tests, along with material on sampling, are available in self-study modules accompanied by 35 mm slide/tape programs. (See Reference "Operational Control Tests for Wastewater Treatment Facilities" under Process Control Tests.)

ACTIVATED SLUDGE

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ACTIVATED SLUDGE

Worksheet 1 - Review of Concepts and Components

1. Who were the two wastewater chemists who discovered the activated sludge process in 1914?

   ____________________ and ____________________

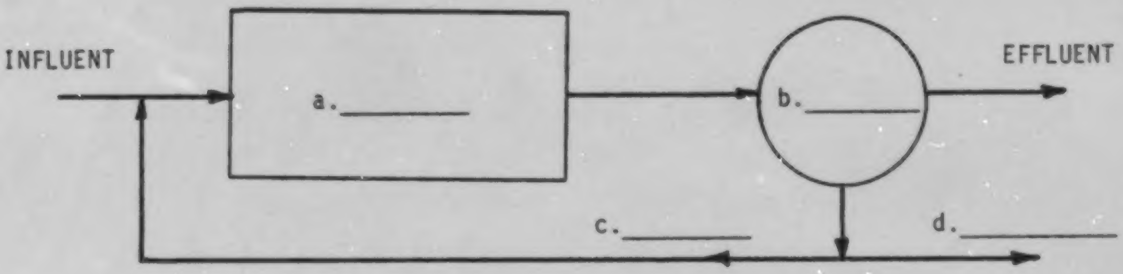
2. Define the activated sludge process.

3. The three major control variables for the activated sludge process are:

   ______________________________, ______________________________, and

   ______________________________.

4. Identify the basin and the flows indicated on the diagram of an activated sludge process plant below:



5. The mechanical aerator with vertical blades attached at the periphery of a circular flat plate that rotates creating a hydraulic jump is the

   ____________________________________.

6. The mechanical aerator that has an impeller located near the surface that forces liquid from the top to the bottom and entrains air is the ________________________.

7. _________________ type aerators combine the diffused air process and the mechanical aerator process.

8. Describe one advantage and one disadvantage of each of the following aeration systems:

   a. Diffused air:

   b. Fine air diffuser:

   c. Coarse air diffuser:

   d. Surface aerators:

9. Pure oxygen can be supplied to ______________________ reactors or to _______________ tanks.

10. Both _______________ and ___________________ shaped clarifiers are often used in activated sludge systems.

11. Design surface loading rates for secondary clarifiers average are _____________________ and weir overflow rates are between _____________ and _____________________________.

12. List two methods of removing sludge from a secondary clarifier.

    a.

    b.

ACTIVATED SLUDGE

Worksheet 2 - Activated Sludge Variations and Modes

1. Process variations are usually defined by three major process variables. These are:

   ____

   ____

   ____

2. The four classic variations are:

   ____

   ____

   ____

   ____

3. Give the expected F/M ratios for each of the following variations:

   High rate:

   Conventional:

   Extended aeration:

4. Arrange the following variations in order of lowest to highest sludge age by placing 1, 2, or 3 in front of the name.

   _____ Conventional

   _____ Extended aeration

   _____ High rate

5. Draw and label a diagram of a contact stabilization plant:

6. Which of the four variations is expected to yield the most sludge?

____

7. Calculate the loading factor if the following conditions exist:

Detention time = 6 hrs
MLSS = 2000 mg/L
F/M = 0.25

8. The operational mode where the contents of the tank are theoretically uniformly mixed is _______________________.

9. The operational mode where waste flow is added at different points along the aeration basin is called ___________________.

10. The operational mode where air is discharged into the aeration basin in a reduced amount along the basin is called ___________________.

11. The operational mode where the wastewater flows through the system in a slug is called ________________.

Worksheet 3 - Biological Nature of Activated Sludge

1. Define good sludge quality.

2. List four types of microorganisms found in activated sludge floc.

   ____

   ____

   ____

   ____

3. Bacteria break down organic food materials for two main reasons. They are to produce energy for __________ and ________________.

4. Food particles stick to the outside of the bacteria cell in a process called __________. The enzymatically broken down food is then through ____________ taken into the bacteria through the cell membrane.

5. Energy obtained from nutrients entering the cell is converted to new cells by a process called ____________.

6. Energy obtained from nutrients stored within the cell itself and used for cell maintenance is converted by a process called ________________ ____________________.

7. Cellular respiration is also referred to as the ______________________ of the nutrient chemical.

8. Observation of the types and numbers of __________ can help determine the status of the bacterial population.

9. If the following list of microorganisms were to be used as indicators of sludge age, arrange the list in the correct order, from youngest to oldest.

   rotifers, free-swimming ciliates, worms, amoeba, stalked ciliates, flagellates

   a. youngest
   b. ↓
   c.
   d.
   e.
   f. oldest

10. For each of the following characteristics indicate whether they represent young (Y) or older (O) cells:

- _____ short generation time
- _____ low degree of motility
- _____ white, billowy foam
- _____ fast settling
- _____ low F/M ratio
- _____ low Volatile SS production

11. Explain what a "two-sludge" system is.

12. Why does sludge flocculate better as it gets older?

13. Is the presence of filamentous bacteria in floc beneficial or detrimental? Explain.

14. Floc with low SVI, small, dense and over-oxidized is called ____________ floc.

15. Floc which is large and feathery, has many external filaments, and an SVI greater than 200 is called __________________.

16. Normal floc is about __________ microns in diameter and has an SVI of __________________.

ACTIVATED SLUDGE

Worksheet 4 - Sludge Quality

1. Good quality sludge can be defined as the right mixture of ____________ that produce a good ____________.

2. Factors that affect growth and thus sludge quality are often referred to as ____________ ________________.

3. List three items that can be visually assessed at the aeration tank.

    ____

    ____

    ____

4. Describe the appearance of good sludge in the aeration basin.

5. Describe a young sludge in terms of:

    a. foam appearance

    b. settling characteristics

6. Describe an old, over-oxidized sludge:

    a. foam appearance

    b. settling characteristics

7. Describe the difference between solids lost due to hydraulic washout and that due to bulking sludge.

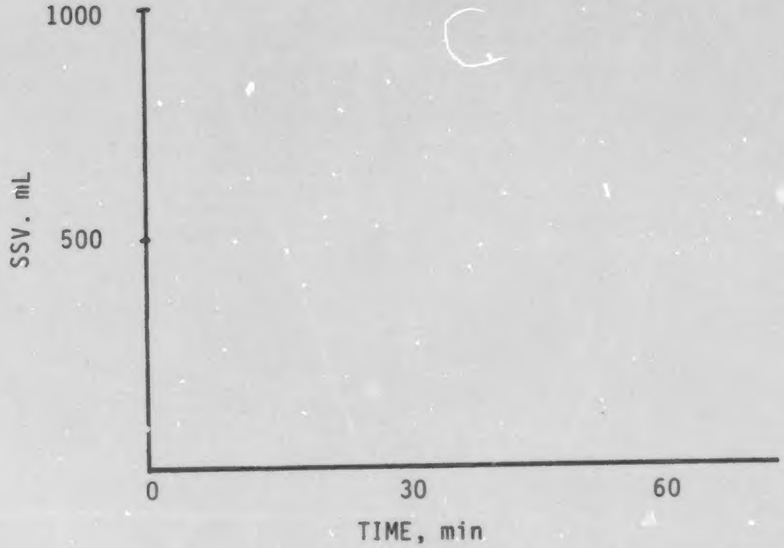
8. Distinguish between straggler and pin floc.

9. BOD loading for activated sludge systems range from ______ lb BOD per lb of MLVSS for high rate to ______________ lb BOD per lb of MLVSS for extended aeration systems.

10. How is sludge yield defined?

11. Define respiration rate.

12. On the graph below draw a settling curve for an under-oxidized (young) sludge using a solid line and a curve for an over-oxidized (older) sludge using a dashed line.



13. Calculate SVI for the following system:

30 min. settleability = 300 mL/L
MLSS = 2700 mg/L

14. Listed below are oxidation pressure forces and indicators. For each of the items listed indicate whether they represent over-oxidized (O) or under-oxidized (U) sludge.

____ high D.O.

____ low MLSS

____ low F/M

____ high MCRT

____ pin floc

____ rapid settling

____ high SVI

____ white, fluffy foam

____ high respiration rate

____ low turbidity in effluent

ACTIVATED SLUDGE

Worksheet 5 - Return Sludge Control

1. In the activated sludge process sludge is returned to the ________________ from the _____________.

2. The return sludge provides sufficient _________ to meet the incoming food.

3. Define the following terms:

   CSFD:

   RSF:

   RSC:

4. Calculate return sludge flow in MGD by the desired MLSS method if:

   MLSS desired = 3000 mg/L
   Flow, Q = 1.2 MGD
   RSC = 10,400 mg/L

5. Calculate CSFD if:

   RSF = 0.6 MGD
   RSC = 10,400 mg/L
   MLSS = 3000 mg/L

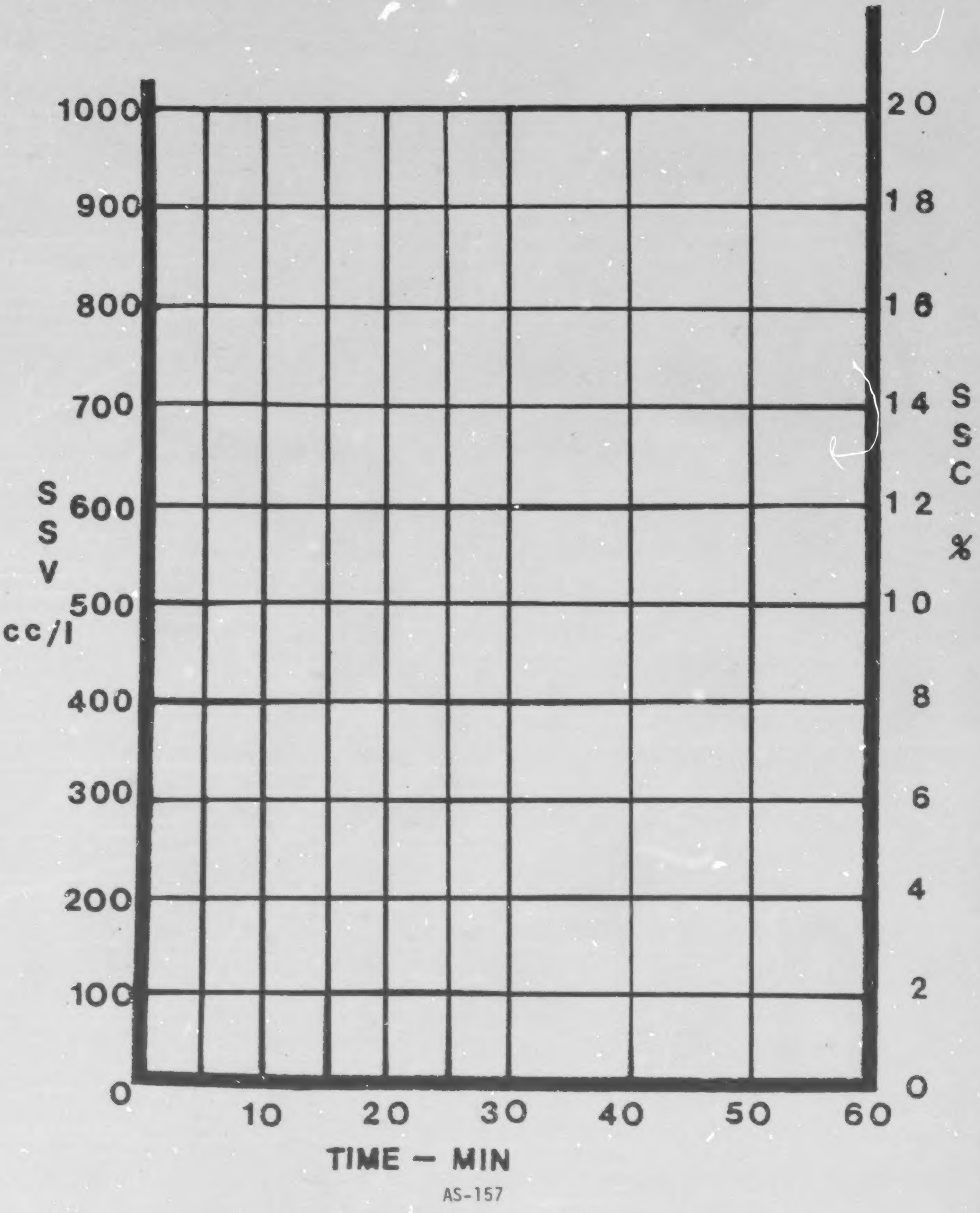
6. Calculate return sludge flow (RSF) by the SVI method if:

Q = 1.2 MGD
MLSS = 3000 mg/L
SVI = 100 mL/g

7. From the following settleometer data calculate SSC and plot the data on the attached graph.

ATC = 3.8%

TIME, min	SSV,mL
0	1000
5	680
10	450
15	350
20	290
25	260
30	230
40	200
50	190
60	190


1000
900
800
700
600
500
400
300
200
100
0
S
S
V
cc/l
20
18
16
14
12
10
8
6
4
2
0
S
S
C
%
10
20
30
40
50
60
TIME — MIN

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ACTIVATED SLUDGE

Worksheet 6 - Waste Sludge Control

1. One of the two major goals of waste sludge control is to regulate the ________ of sludge in the activated sludge system.

2. The second major goal of waste sludge control is to regulate the ________ ____________.

3. ________ ____________ is the term used to describe the process of keeping track of where the sludge is in the system and how much is in each location.

4. A material balance program should be able to answer the three following questions:

   ____

   ____

   ____

5. List five of the 9 methods used to evaluate the presence of excess sludge.

   ____

   ____

   ____

   ____

   ____

6. Generally if F/M is higher than normal the response should be to (reduce or increase) wasting.

7. Generally if MLVSS is lower than normal the response should be to (reduce or increase) wasting.

8. Generally if the MCRT is lower than normal the response should be to (reduce or increase) wasting.

9. Increasing wasting tends to (increase or decrease) sludge age.

10. What is the value of using trend charts in determining waste sludge flows?

11. If the trend charts indicate that the MCRT should be adjusted to 5.0 days and there are currently 120,000 lbs of VSS in the total system, what should the wasting be in lbs/day?

12. If the trend charts indicate that wasting should be adjusted so that the F/M is 0.40 and the BOD loading per day is 50,000 lbs/day, what should the MLVSS be in a 5.5 Mgal aeration tank?

ACTIVATED SLUDGE

Worksheet 7 - Trend Charts, Testing, and Data Management

1. Graphs of various plant and control data parameters plotted for each day are called __________ __________.

2. The __________ average is an average of a prescribed number of previous day's data plotted each day, using a newly generated average each day.

3. Calculate the seven day moving average for the following data:

Day/Date	24-hr Avg. Value
M 4/1	6
T 4/2	6
W 4/3	2
H 4/4	5
F 4/5	6
S 4/6	2
S 4/7	10
M 4/8	8
T 4/9	7
W 4/10	28
H 4/11	6
F 4/12	6
S 4/13	1
S 4/14	5
M 4/15	7
T 4/16	6
W 4/17	6
H 4/18	15
F 4/19	8
S 4/20	4
S 4/21	6

Worksheet 8 - Trouble-shooting

Camp Swampy Sewage Treatment Plant

You have just assumed the position of Plant Superintendent of the Camp Swampy STP. Historical data on plant operations are badly inadequate. The NPDES permit limitations of 30 BOD and 30 TSS have frequently been exceeded (which is why you got the job). Based on the following information, what do you think should be done to improve operations? Please consider both long-term and short-term solutions.

Plant Description:

Primary Clarifier

The plant has no primary clarifier. This has caused serious problems in the fouling of the propeller-type flow meters used in the plant.

Aeration Tank

The aeration tank is rectangular and designed to operate in either the plug flow or contact stabilization mode. Surface mechanical aerators are used for aeration. D.O. is controlled by a variable effluent weir which controls the liquid level in the aeration tank. No problem has been experienced in maintaining adequate D.O.

Final Clarifier

The final clarifier is circular with center well feed and peripheral effluent weirs. Scum baffles and a scum removal mechanism are provided. Sludge is removed from the clarifier by draft tubes to the return sludge wet well.

Return Sludge Flow

Return sludge is pumped from the return sludge wet well by a centrifugal pump to the aeration tank. Return flow is controlled by throttling a butterfly valve in the return flow line to the aeration tank. The return flow meters, which are of the propeller type, will not operate because of fouling.

Aerobic Digester

The aerobic digester is circular with a fixed surface mechanical aerator. Digested sludge is hauled by tank truck to a land disposal site. Because of the fixed surface aerator, the digester must be supernated before sludge can be wasted.

Wasting

Historically, the volume of sludge wasted was determined by the volume that could be made available in the digester by supernating and hauling. Sludge is transmitted from the return sludge line to the aerobic digester by opening the waste valve on the waste transfer line. A propeller type flow meter in the waste transfer line will not work because it rapidly becomes fouled. Waste volume is determined by the inches pumped to the digester.

Meters

Plant influent is metered by a Parshall Flume which is in good operating condition. The return sludge flow meter and the waste sludge flow meter, which are of the propeller type, will not operate because of propeller fouling.

CAMP SWAMPY SEWAGE TREATMENT PLANT

Partial Summary of Plant Status

Settleometer Test

Time	SSV	SSC
0	1000	4.0
5	500	8.0
10	310	12.9
15	240	16.7
20	200	20.0
25	180	22.2
30	170	23.5
40	165	24.2
50	165	24.2
60	165	24.2

Centrifuge Test

ATC = 4.0 RSC = 10.0

$$CSP = \frac{ATC}{RSC-ATC} = 66.6\%$$

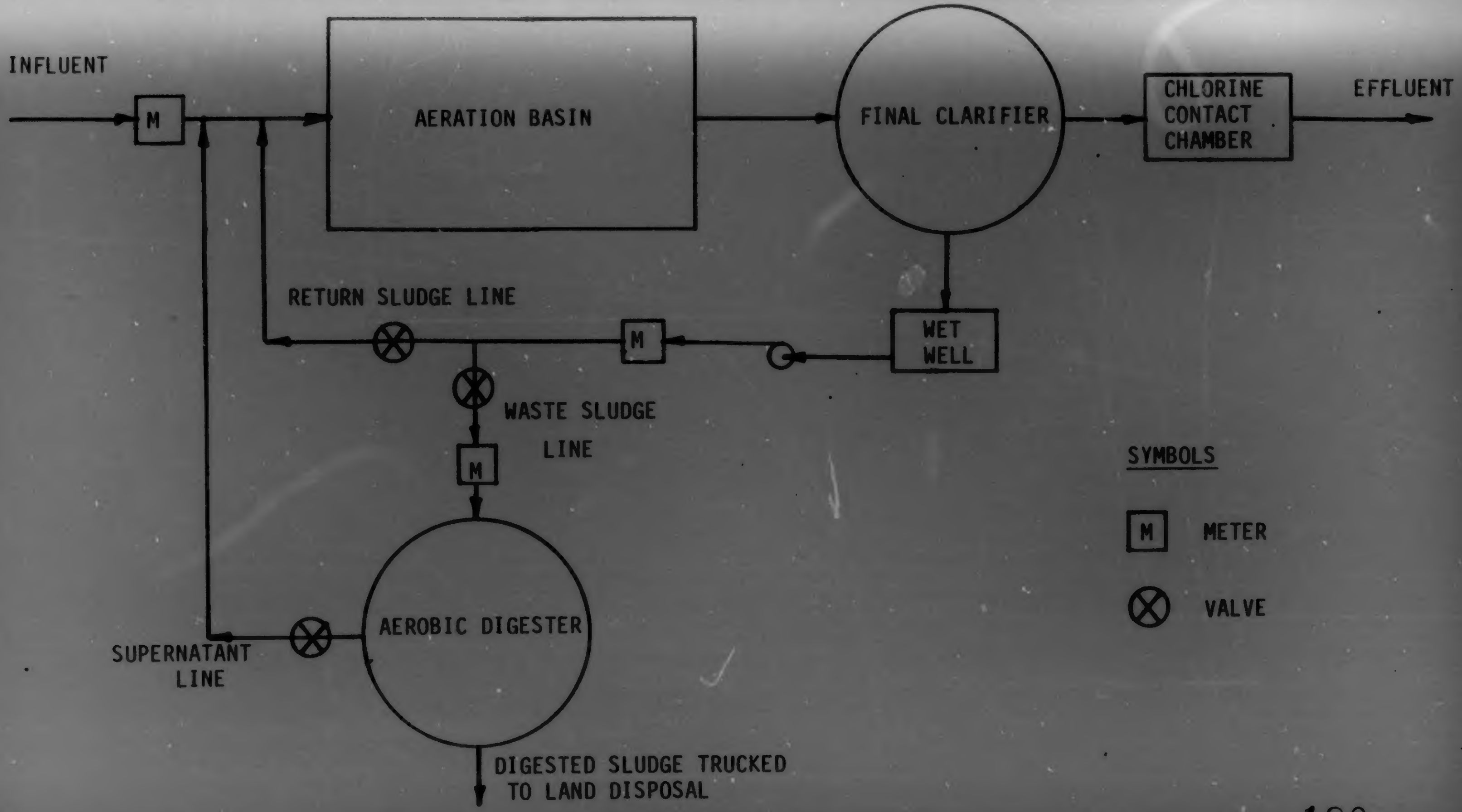
Influent/Effluent Parameters

	Influent	Effluent
BOD	210	23
TSS	170	26
Turbidity (Initial)	-	9.6

Physical Observations

Aeration Tank:	Dark brown greasy scum on surface.
Clarifier:	Ashing and straggler floc with surface scum accumulations.

CAMP SWAMPY SEWAGE TREATMENT PLANT
FLOW DIAGRAM



INFLUENT
M
AERATION BASIN
FINAL CLARIFIER
CHLORINE CONTACT CHAMBER
EFFLUENT
RETURN SLUDGE LINE
M
WET WELL
WASTE SLUDGE LINE
M
AEROBIC DIGESTER
SUPERNATANT LINE
DIGESTED SLUDGE TRUCKED TO LAND DISPOSAL
SYMBOLS
M METER
VALVE

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